

The background of the slide is a composite image of space. In the top left, a portion of Earth is visible. Below it is the Moon. The rest of the background is a deep space scene with a purple and blue nebula and numerous stars. The James Webb Space Telescope is shown in the lower right, its large segmented mirror reflecting the colorful nebula. The telescope's structure, including its sunshades, is clearly visible.

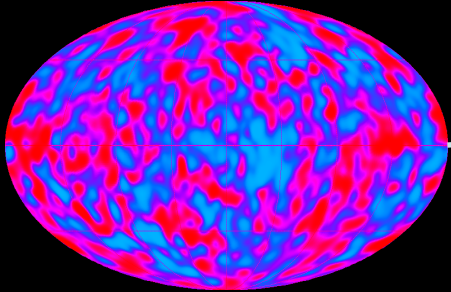
Looking back in time: Extracting information from star light

Matt Greenhouse

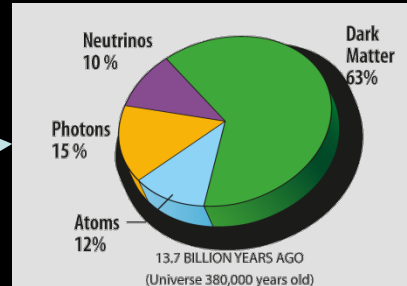
James Webb Space Telescope Project Office
NASA Goddard Space Flight Center

How did the universe evolve to produce the Earth – our world?

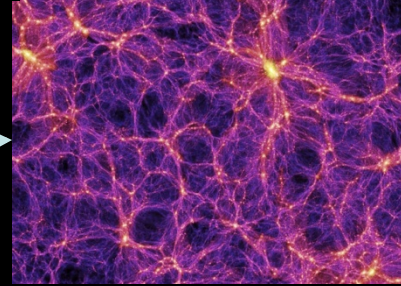
Oldest Light



Composition Then



Cosmic Web (simulation)



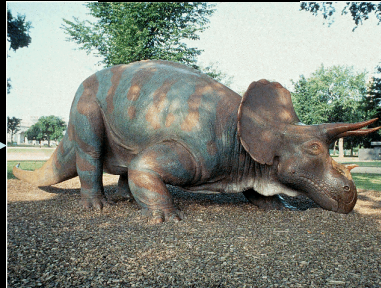
Irregular Galaxy Shapes



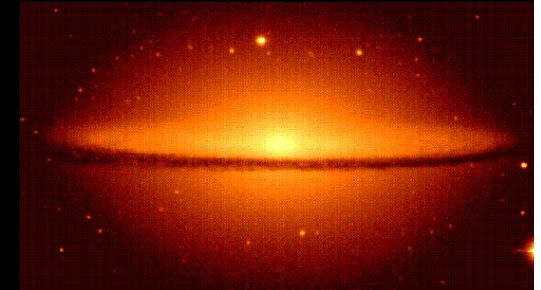
Planets With Liquid Water



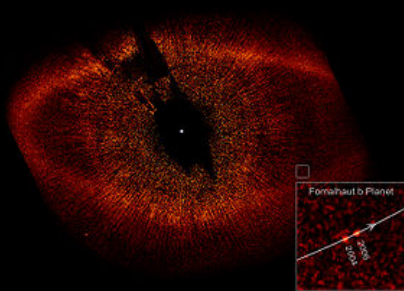
Life



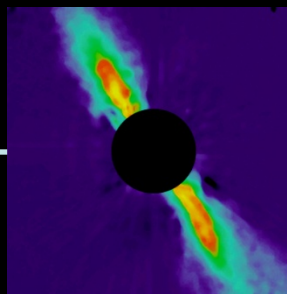
Symmetric Galaxy Shapes



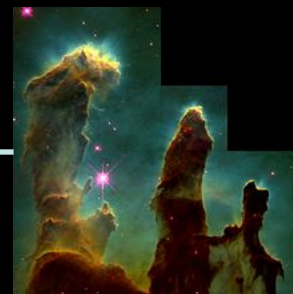
Extra-Solar Planets



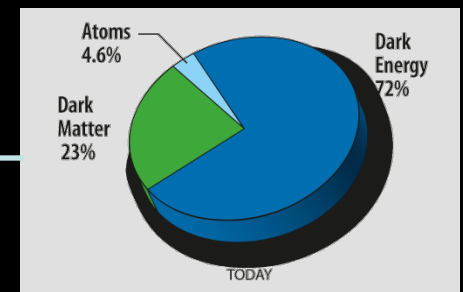
Stellar Debris Disks



Star Birth



Composition Now

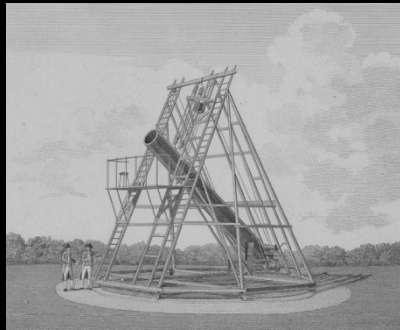


Humanity's quest to understand its origins is as old as recorded history.

New tools for discovery are providing insights and questions at a rate that is unprecedented in human history



Astrolabe
Circa 1090 A.D.



Reflecting Telescope Circa 1800



Spectroscopy Circa 1950



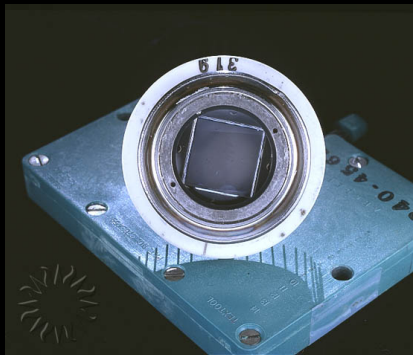
**NASA's Great
Observatory program**
Circa 1990



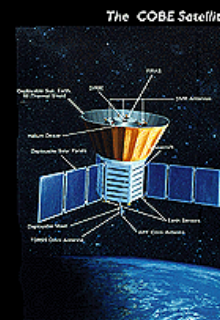
Armillary Sphere
Circa 1500



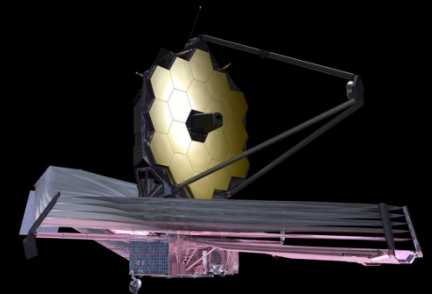
Photographic film replaces eye
Circa 1930



Electronic detectors replace film
Circa 1980

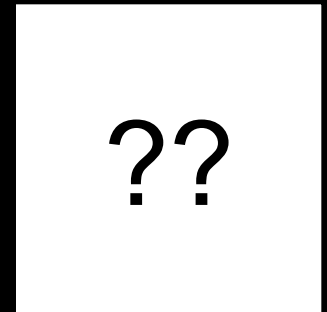
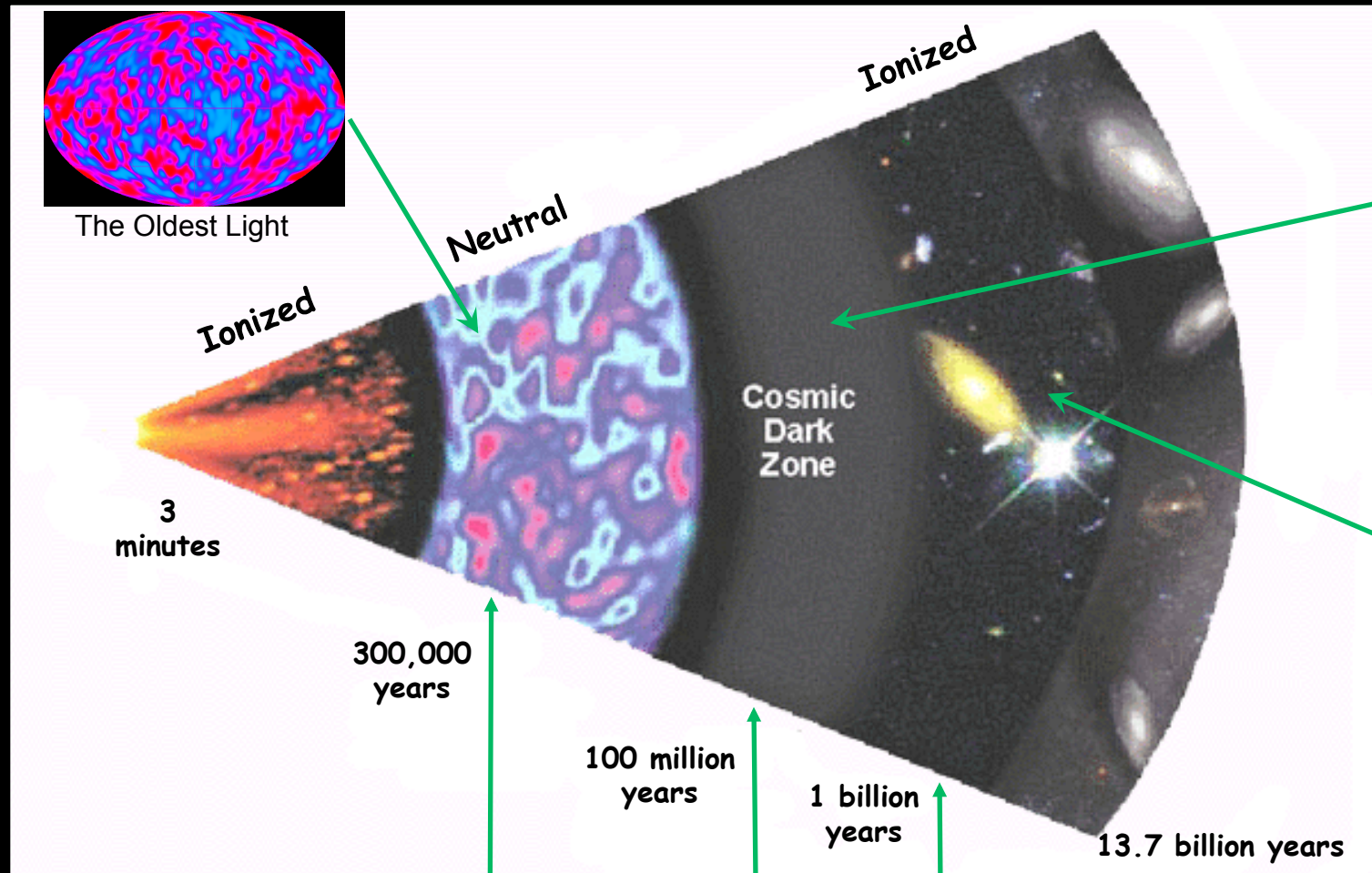


First light
Circa 1990



James Webb Space Telescope
To be launched 2018

Space telescopes are astronomer's most powerful tools for exploring the fossil record of the universe



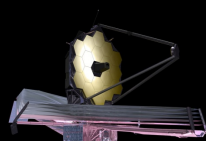
The Most Distant Objects Yet Seen



WMAP



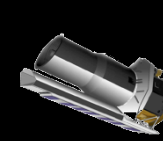
COBE



JWST



HST



Spitzer

Traveling back in time is the stuff of science fiction, but looking back in time is science fact



HAND



1 m

0.000000003

EARTH



7000 km

0.02 sec

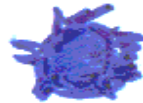
SUN



150,000,000 km

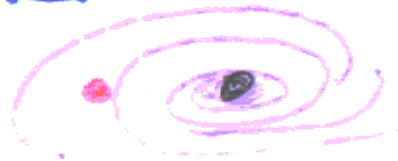
500 SE

STAR



4 YRS

GALAXY



25,000 YRS

BIG BANG



15,000,000,000 YI

Learning how to measure distance in astronomy was key to discovering that our galaxy is one among many

Planetary Nebula IC 418



Edwin P. Hubble
1889-1953



Hubble
Heritage

PRC00-28 • NASA and The Hubble Heritage Team (STScI/AURA) • HST/WFPC2

Starburst Galaxy NGC 3310

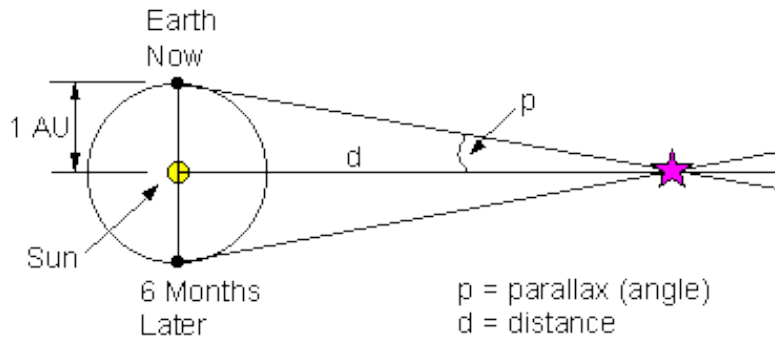


Hubble
Heritage

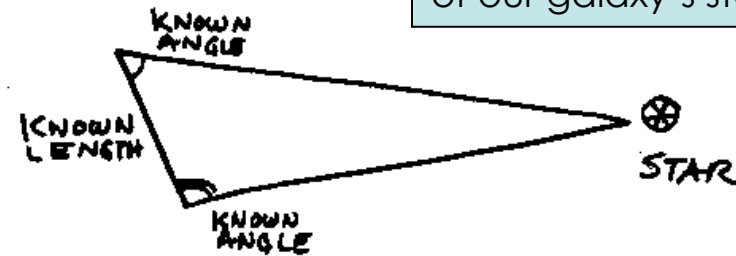
NASA and The Hubble Heritage Team (STScI/AURA)
Hubble Space Telescope WFPC2 • STScI-PRC01-26

Which object further away? How can you tell?

Measuring distance in astronomy requires clever techniques and a little bit of math ...



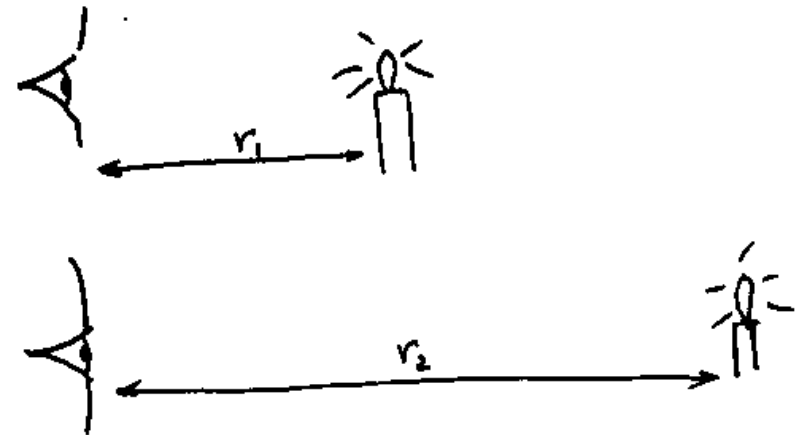
1. TRIANGLES



This technique enables distance measurement to about 3000 light years reaching only one millionth of our galaxy's stars

This technique enables measurement of distances a million times greater than the above

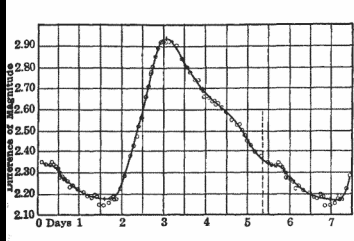
2. STANDARD CANDLES



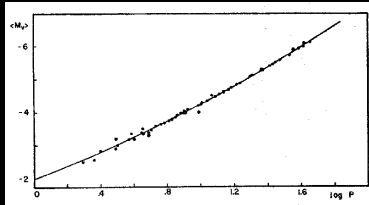
$$\frac{\text{BRIGHTNESS}_1}{\text{BRIGHTNESS}_2} = \frac{r_2^2}{r_1^2}$$

Examples of “Standard Candles”

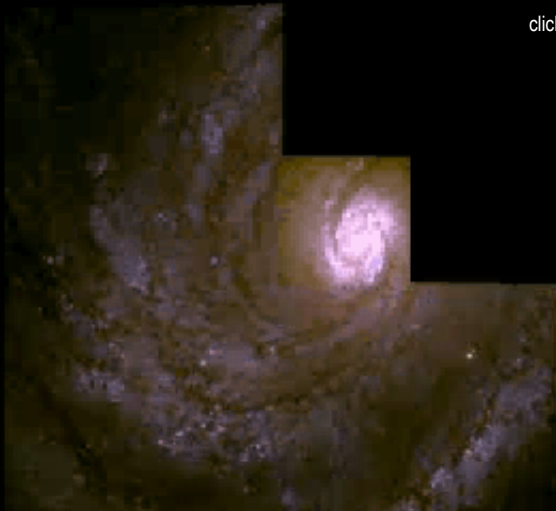
Cepheid Variable Stars: known period-brightness relation.



Henrietta Leavitt 1868 - 1921



Suitable for galaxies close enough to us that individual stars can be seen

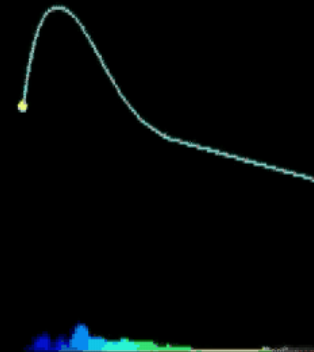


click animation

Standard Candles are astronomical sources for which the intrinsic brightness is known a priori.

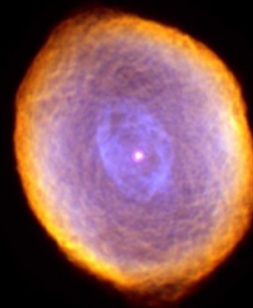
Supernovae: known maximum luminosity. Suitable for distant galaxies.

click animation



By measuring distance with “standard candles” Hubble discovered that many “nebulae” are outside our galaxy and are, in fact, other galaxies

Planetary Nebula IC 418



Hubble
Heritage

PRC10-26 • NASA and The Hubble Heritage Team (STScI/AURA) • HST/WFPC2

“Planetary Nebula”
are within our Galaxy

Starburst Galaxy NGC 3310



Hubble
Heritage

NASA and The Hubble Heritage Team (STScI/AURA)
Hubble Space Telescope WFPC2 • STScI PRC10-26

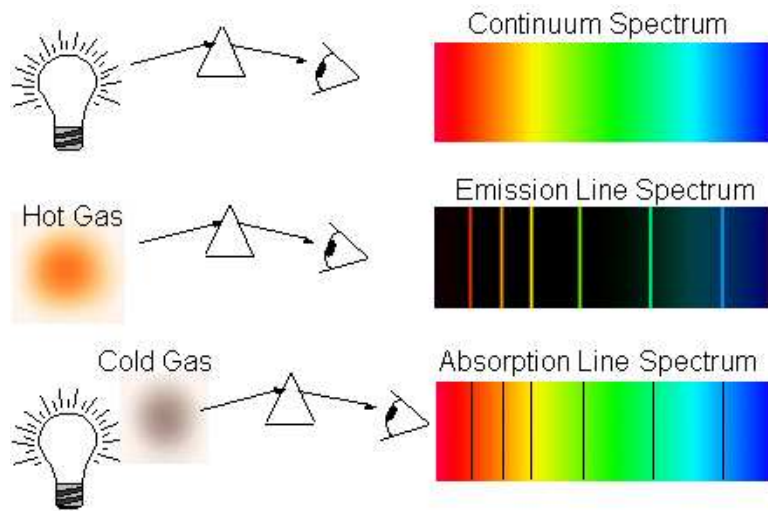
Cepheids in the
Andromeda galaxy
revealed that it is 8
times further than the
most distant star in our
Galaxy

Hubble at Mount Wilson telescope



19 Feb 2013

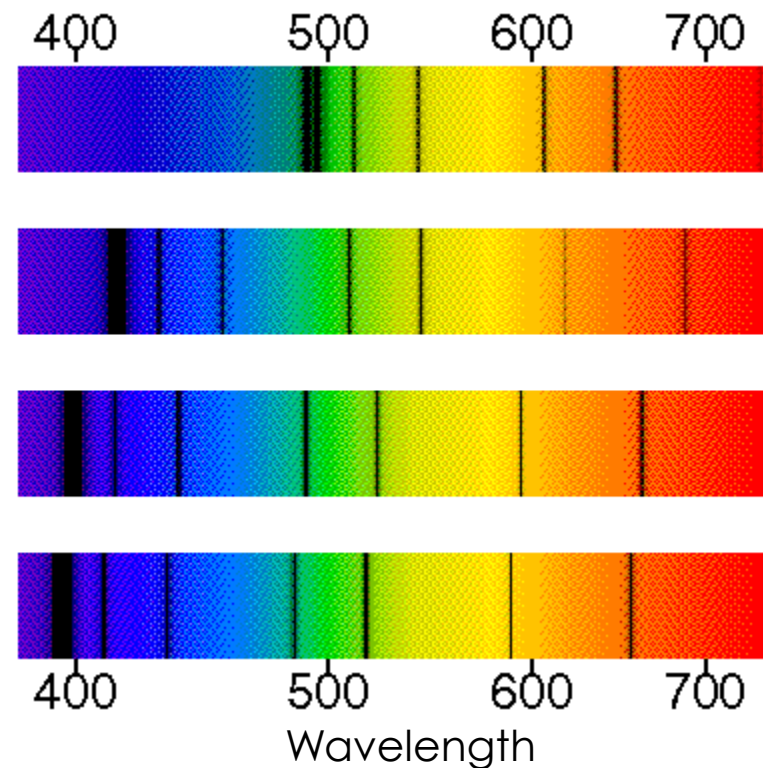
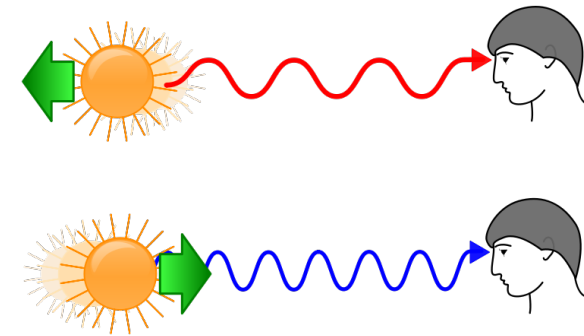
Measuring speed in astronomy also requires clever techniques: Spectroscopy and the Doppler Shift of Light



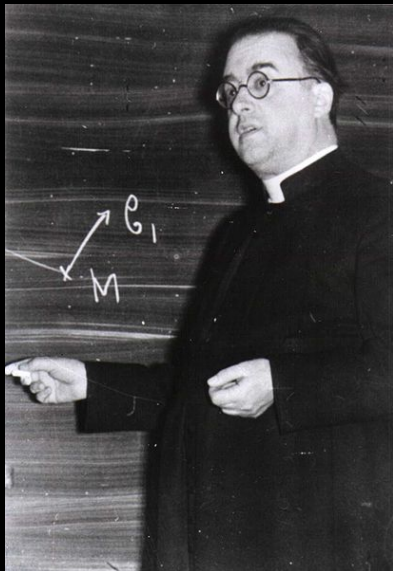
Atoms emit light at discrete wavelengths that can be seen with a spectroscope

This “line spectrum” identifies the atom and its velocity

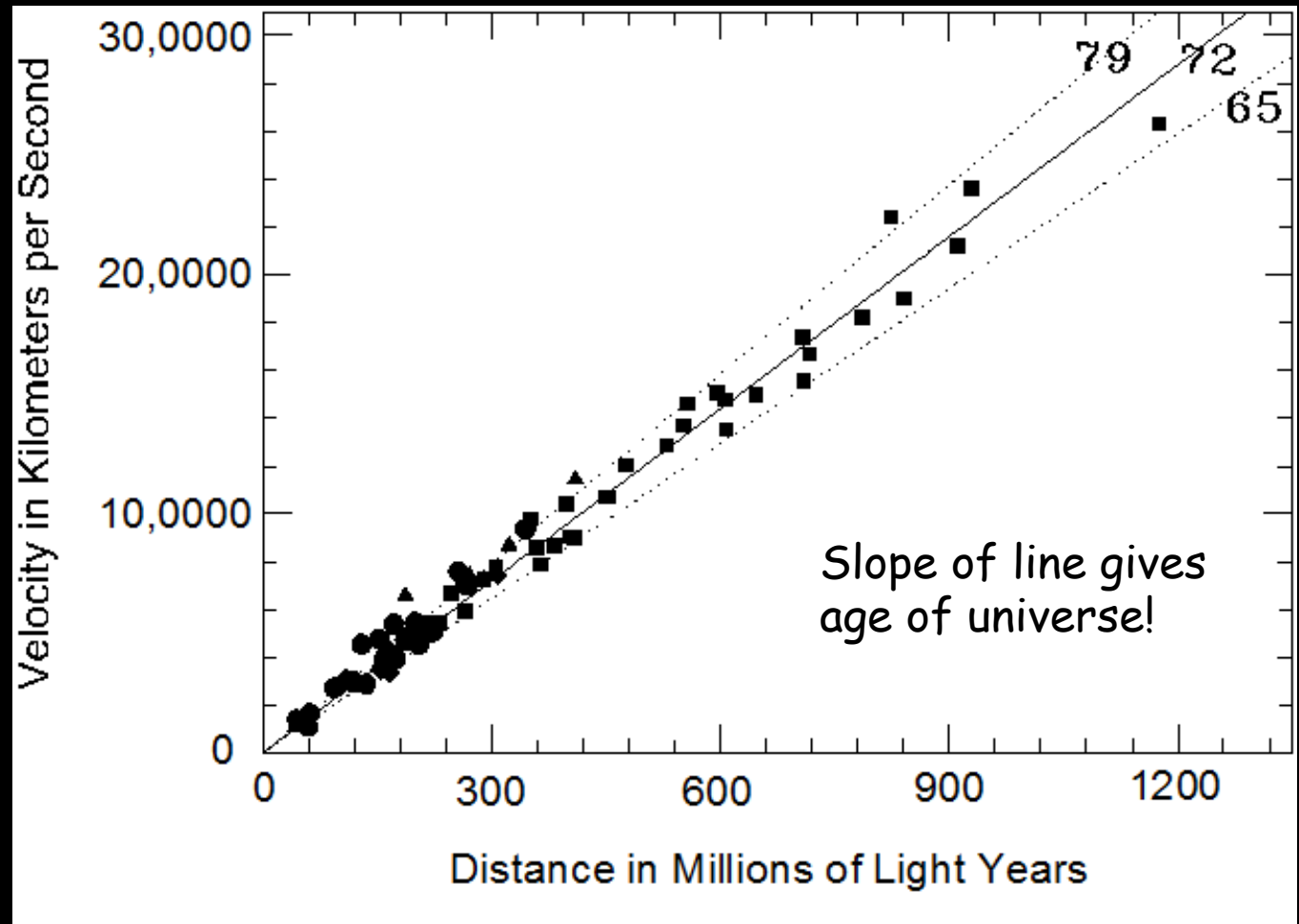
If the source is moving, its wavelength changes in proportion to its velocity



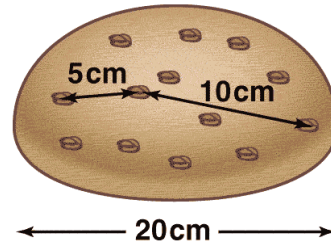
By measuring distance with standard candles and velocity with spectroscopy, Hubble observed Lemaître's prediction that the universe is expanding!



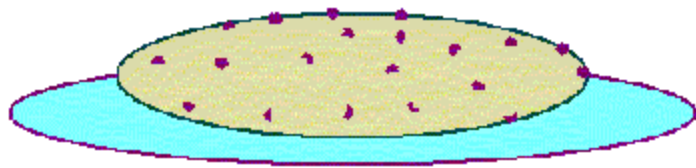
George Lemaître 1894 - 1966



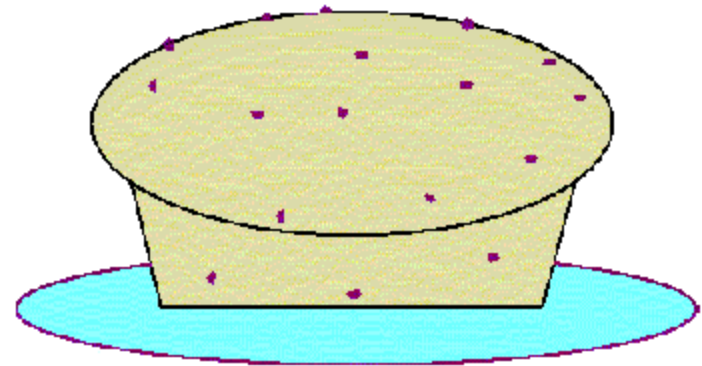
An analogy for the expansion of space



MAP980404



Early time



Later

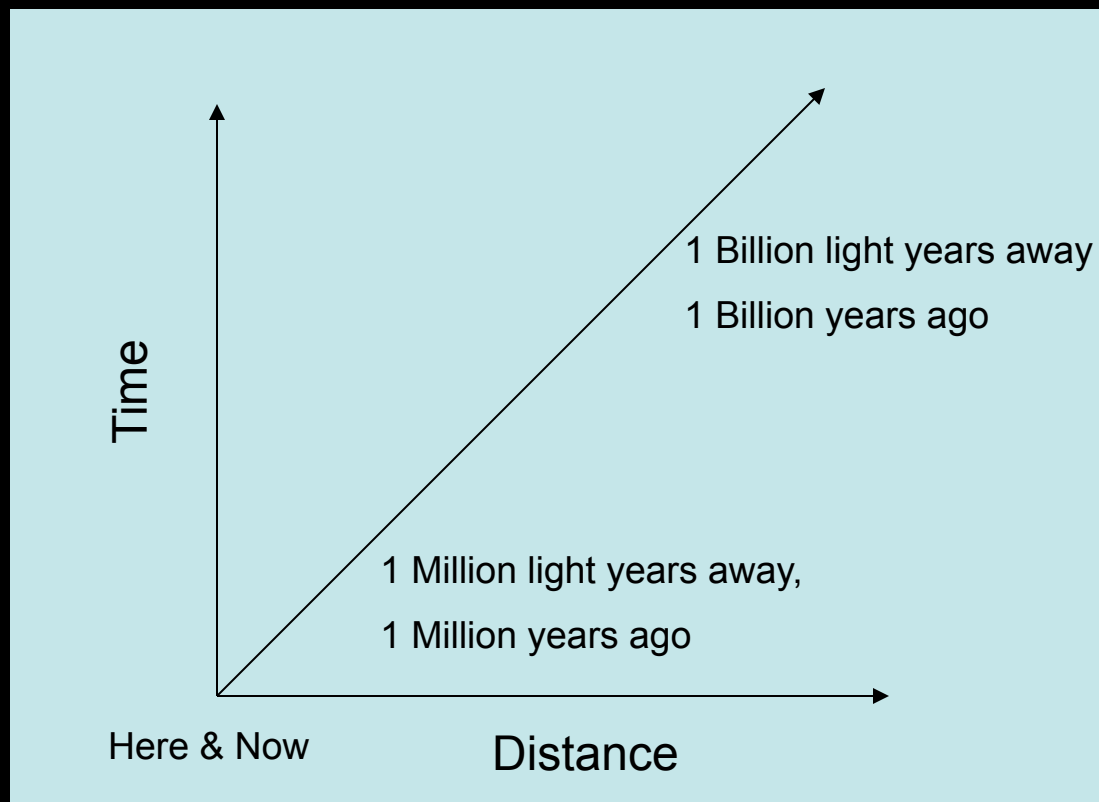
Basic principles that enable astronomers to see the past

Light travels at a fixed speed

So, if a source of light lies at a great distance, then the light takes a long time to reach us

We see astronomical objects as they were when their light was emitted

Hence, we see the objects as they were in the past



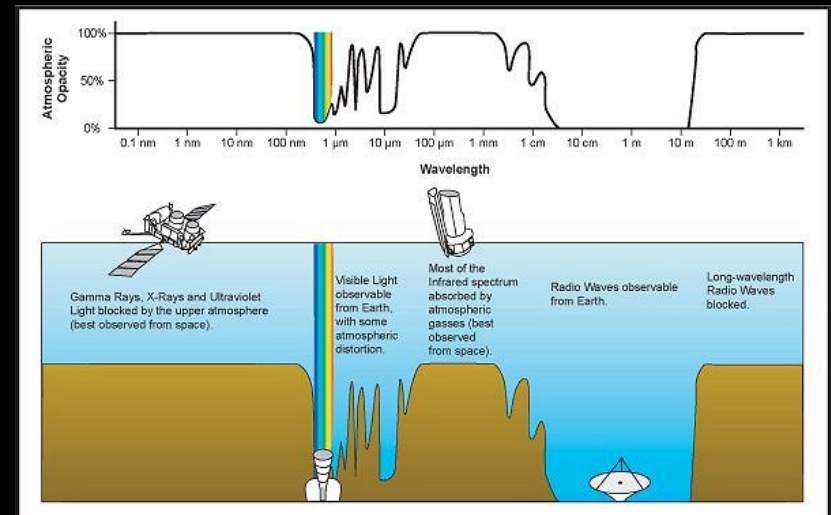
Putting it all together ...

To see backwards in time, to when the Universe was younger:

- We measure the Doppler Shift (redshift) with spectroscopy
- Hubble's law then tells us how far away the source is
- The speed of light tells us how long ago the light was emitted

Very distant sources (galaxies) are faint and red shifted; so, to see the early universe one needs:

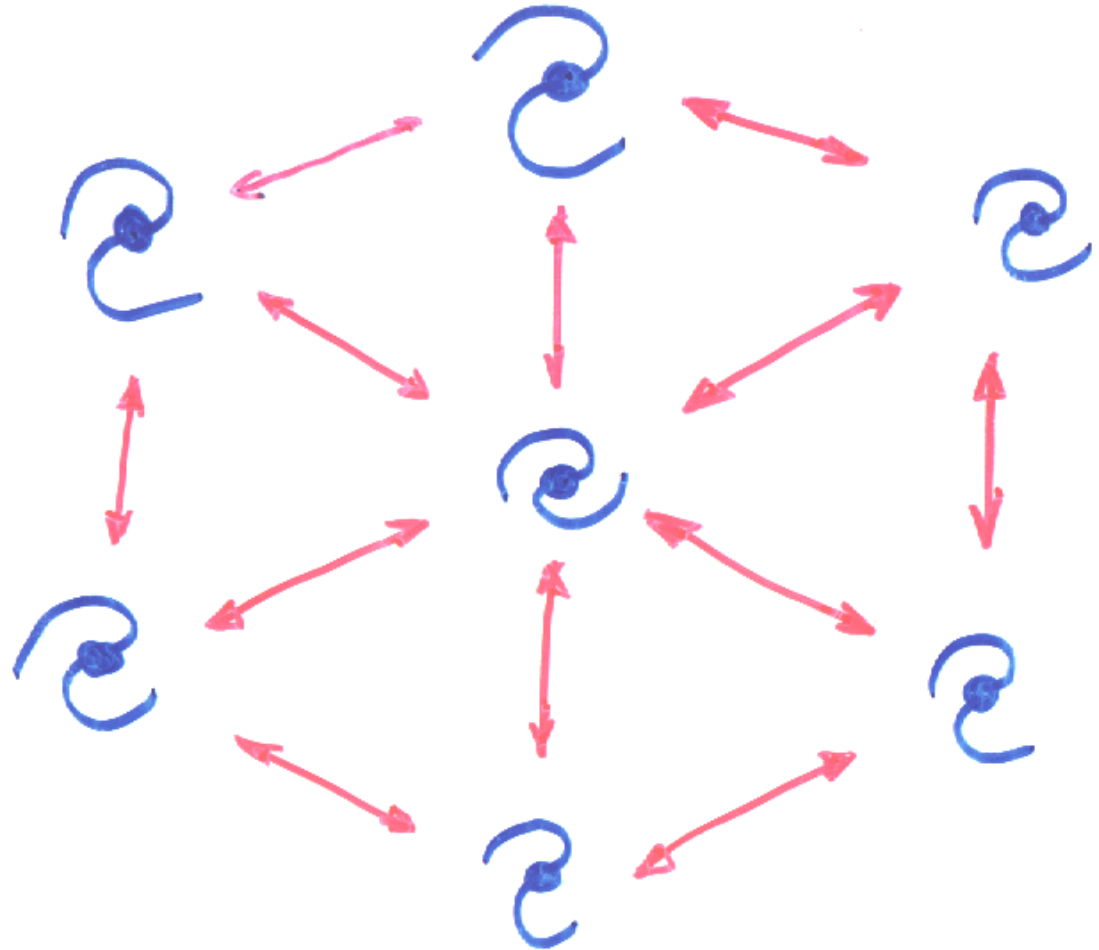
- a powerful (big) telescope
- above the Earth's atmosphere
- with very sensitive electronic detectors



Galaxies attract each other due to gravity, so the expansion should be slowing down -- Right??

To tell, we need to compare the velocity we measure on nearby galaxies to ones at very high redshift.

In other words, we need to extend Hubble's velocity vs distance plot to much greater distances.



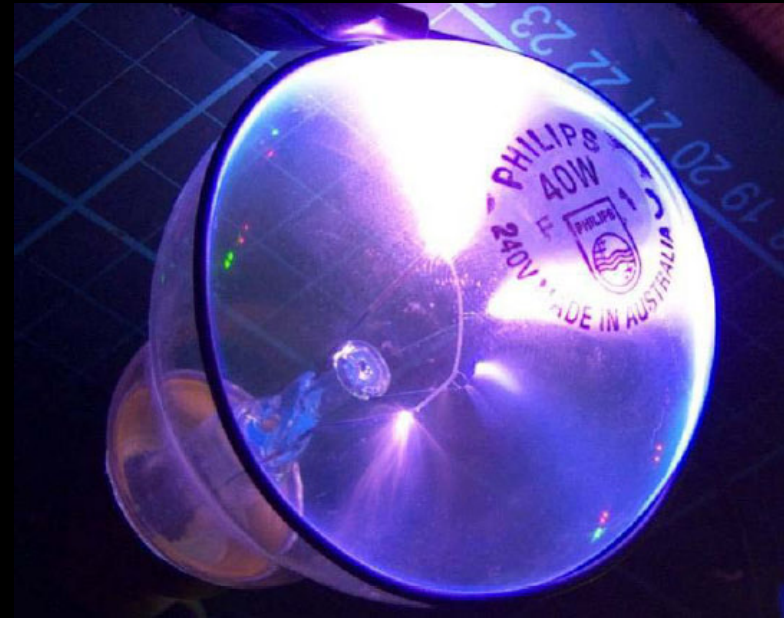
Bright standard candles are needed to extend distance vs velocity measurements to the early universe



Supernovae are giant explosions that, for a short time, can out shine a whole galaxy

They are the furnaces in which all elements heavier than iron are formed

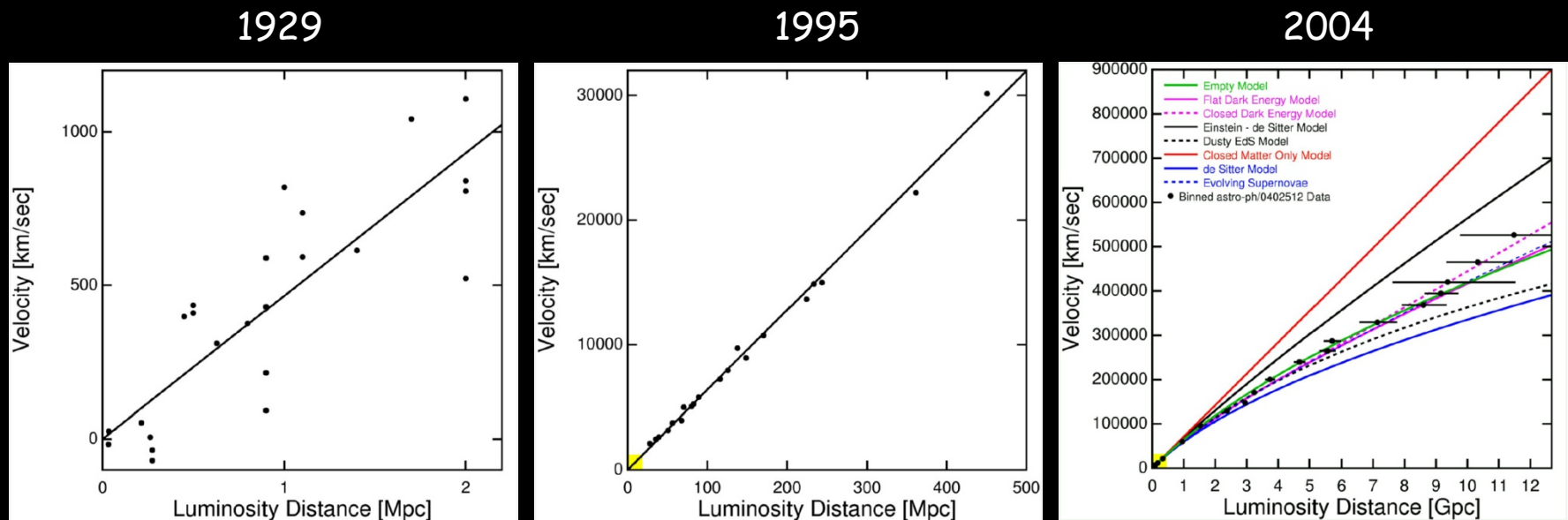
They can be seen at great distances with modern telescopes



Astronomers have recently figured out how to determine the intrinsic brightness of supernovae

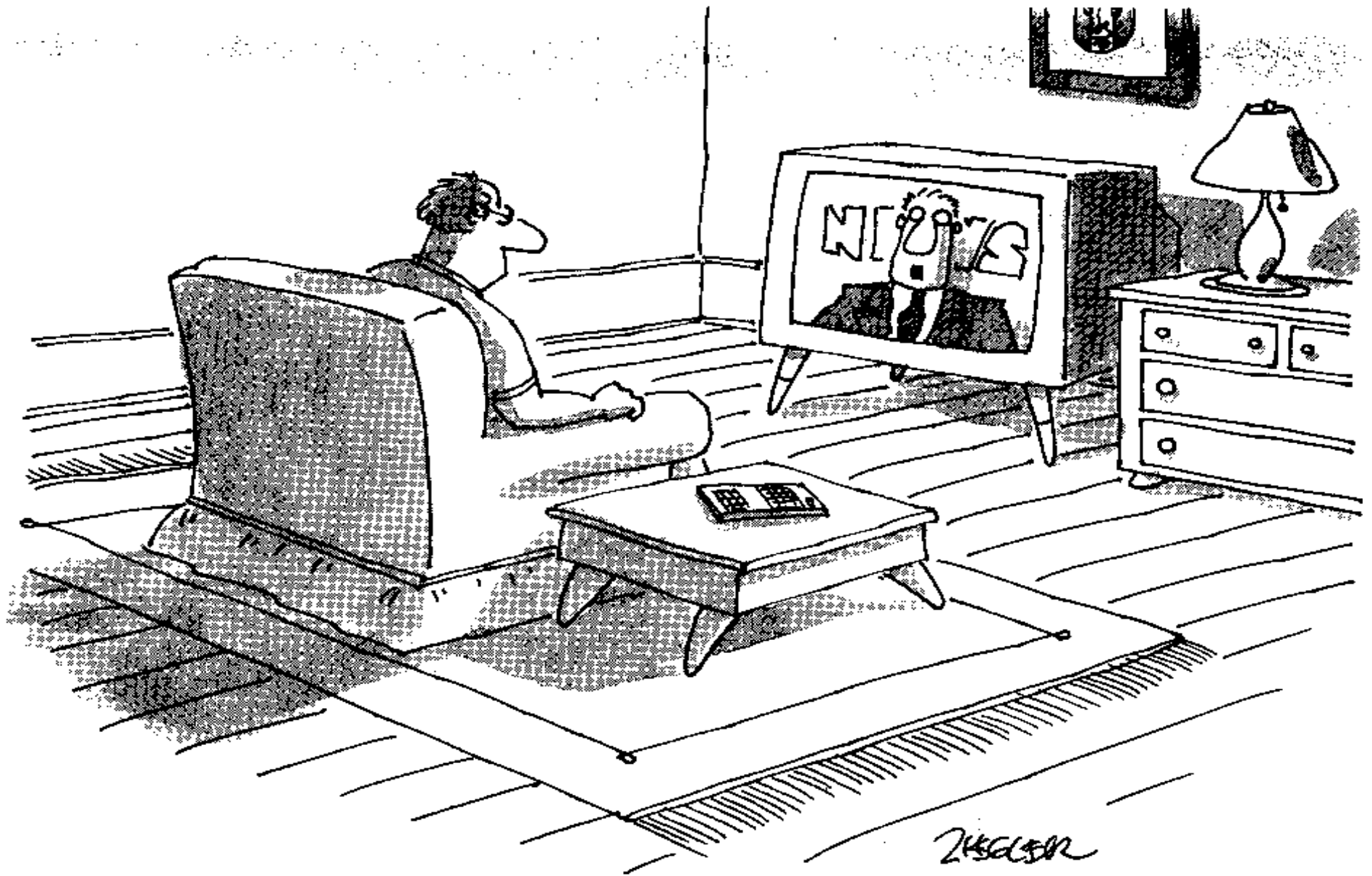
In effect, we can now read their wattage label

Is the expansion of the universe slowing down or staying the same?

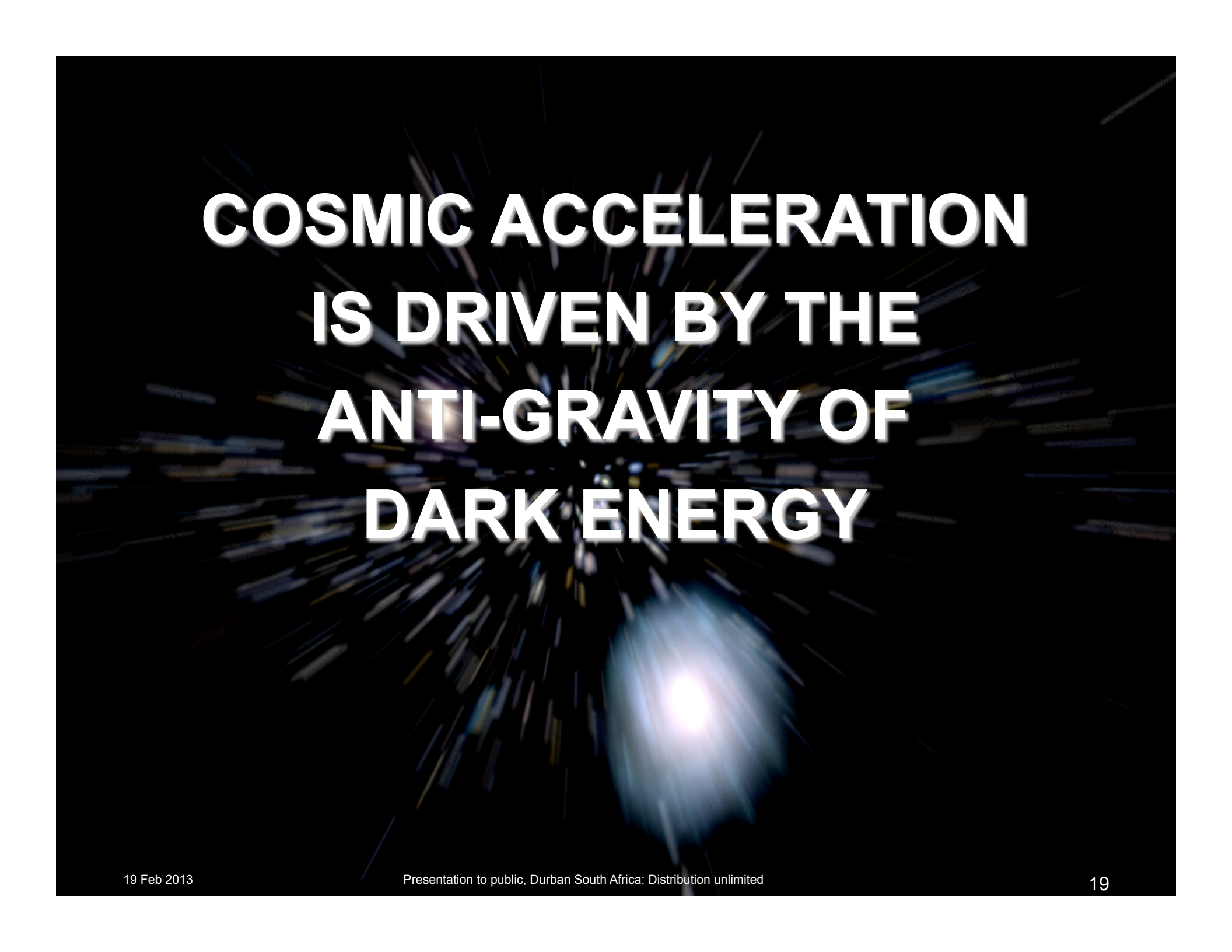


By using supernova as standard candles, astronomers have extended “Hubble’s Law” to distances 10,000 times greater than possible when it was first discovered

This work resulted in a remarkable discovery



"Scientists confirmed today that everything we know about the structure of the universe is wrongedy-wrong-wrong."

The background of the slide is a dark, deep blue space filled with numerous bright, elongated streaks of light. These streaks, representing distant galaxies, are oriented radially, pointing away from a central point, which visually conveys the concept of cosmic expansion or acceleration. The streaks vary in length and brightness, with some appearing as sharp lines and others as more diffuse clouds of light.

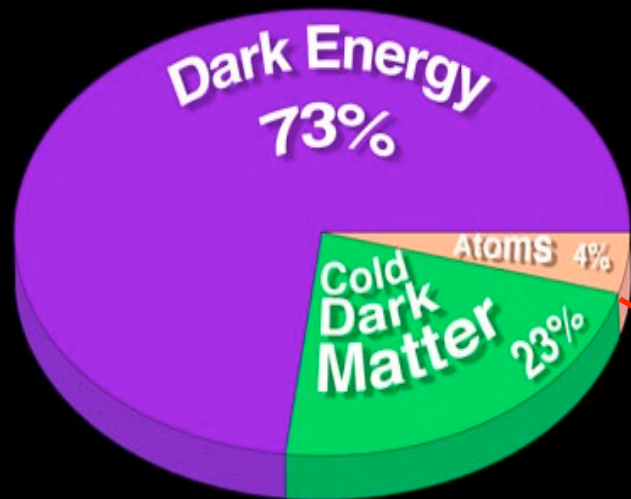
COSMIC ACCELERATION IS DRIVEN BY THE ANTI-GRAVITY OF DARK ENERGY

HUH?

Most of space consists of dark matter and energy that we can't see. We are aware of it, but we don't yet understand it.

Pressure from "Dark Energy" accelerates the cosmic expansion, overcoming gravity

Universal Content

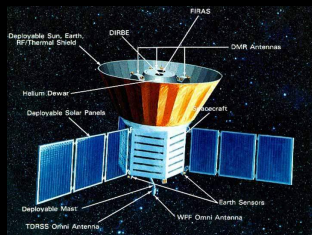


A standard periodic table of elements. It includes atomic numbers, element symbols, and names. The table is color-coded by groups: s-block (yellow), d-block (transition metals, green), p-block (non-metals, blue), and f-block (lanthanide and actinide series, orange). The table is organized into rows and columns, with the lanthanide and actinide series shown separately at the bottom.

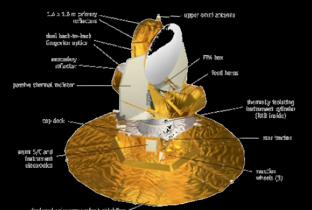
Period	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	H	He																
2	Li	Be	B	C	N	O	F	Ne										
3	Na	Mg	Al	Si	P	S	Cl	Ar										
4	K	Ca	Sc	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	Ga	Ge	As	Se	Br	Kr
5	Rb	Sr	Y	Zr	Nb	Mo	Tc	Ru	Rh	Pd	Ag	Cd	In	Sn	Sb	Te	I	Xe
6	Cs	Ba	La	Hf	Ta	W	Re	Os	Ir	Pt	Au	Hg	Tl	Pb	Bi	Po	At	Rn
7	Fr	Ra	Ac	Th	Pa	U	Np	Pu	Am	Cm	Bk	Cf	Es	Fm	Md	No	Lr	

All the elements (atoms) that we know of make up only 4% of the universe

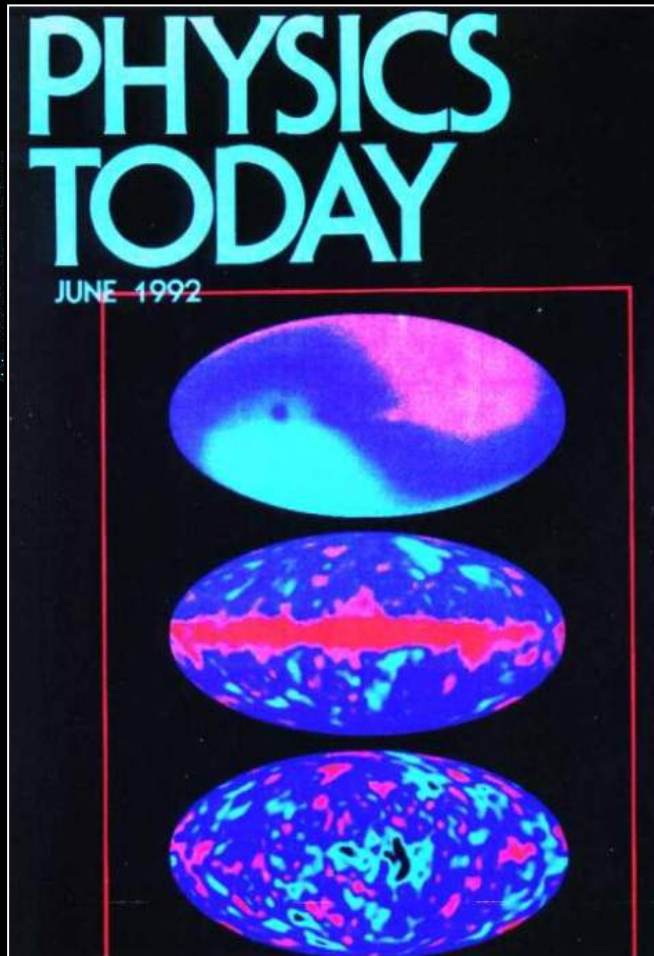
Incredible discoveries are now occurring rapidly due to the development of powerful telescopes in space



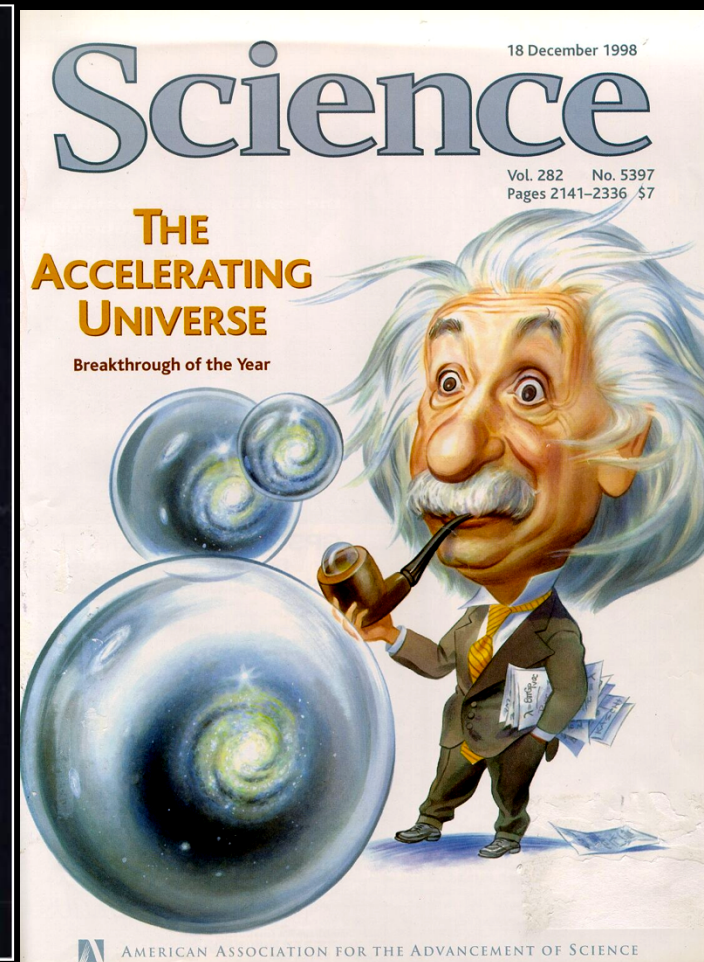
COBE 1989



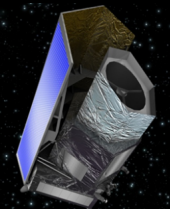
WMAP 2001



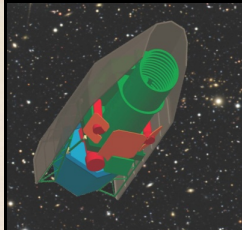
1992: Big Bang theory proven



1998: A new mystery uncovered

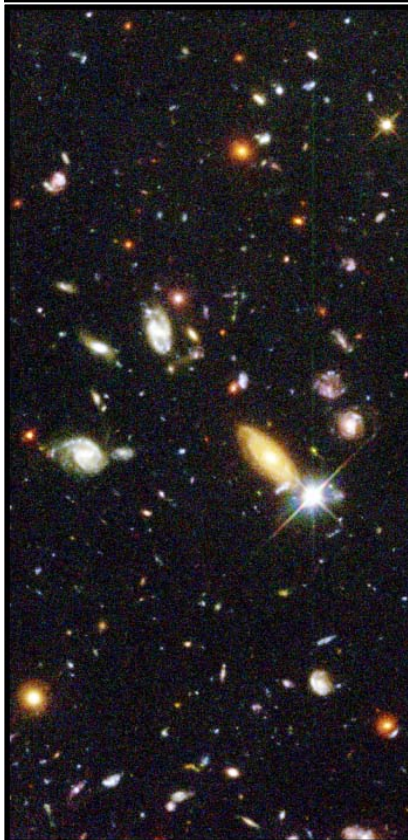


Euclid 2020



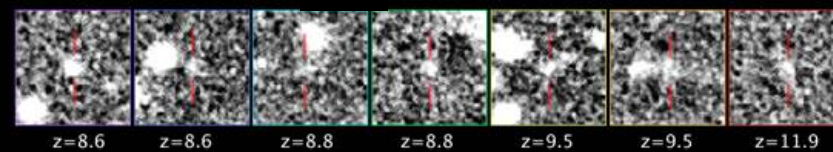
WFIRST

Imaging the first galaxies

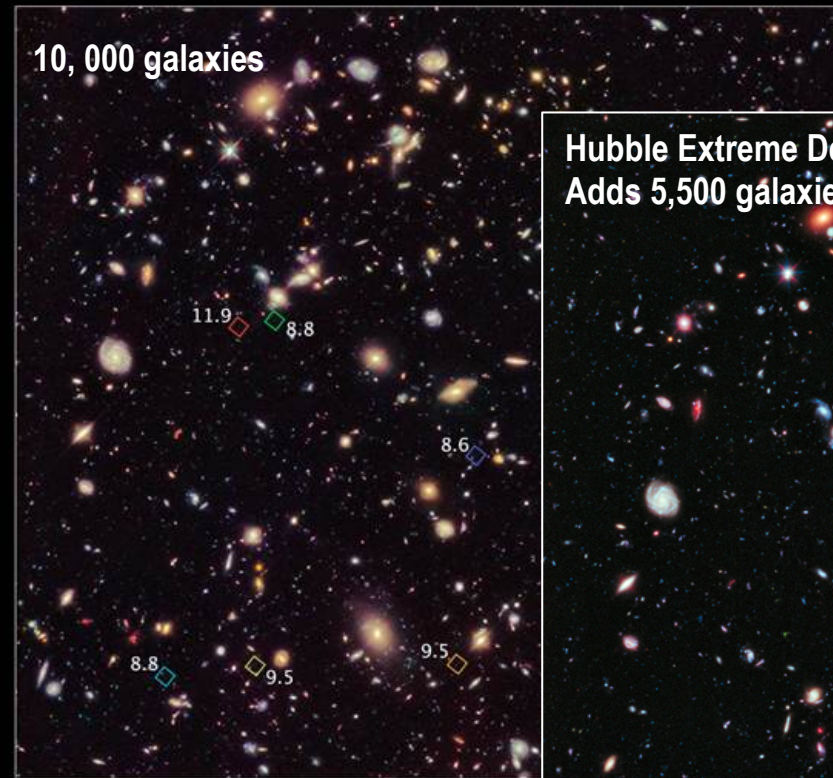


Hubble Deep Field
PRC96-01a · ST ScI OPO · January 15, 1996

Hubble Ultra Deep Field 2 2004

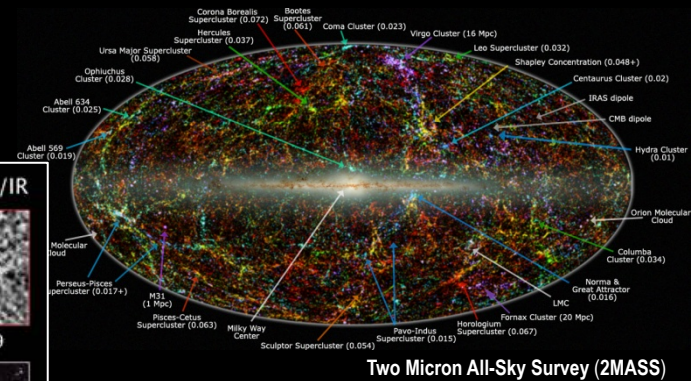


10, 000 galaxies

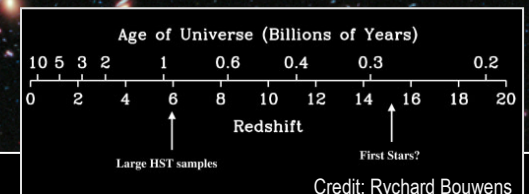
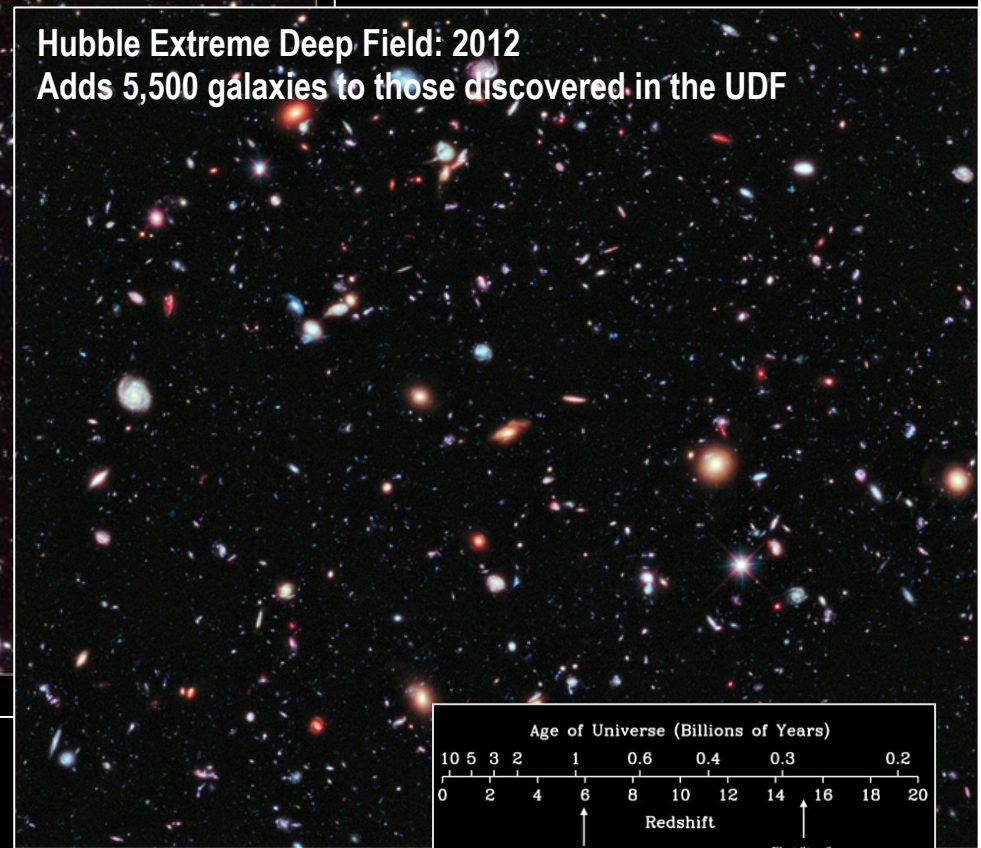


NASA and ESA

Hubble Space Telescope has been pushed to its limits that result from its size and wavelength range

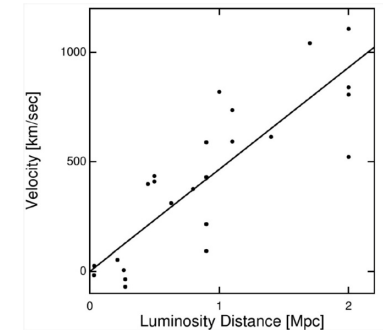
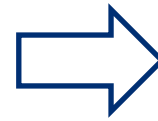


Hubble Extreme Deep Field: 2012
Adds 5,500 galaxies to those discovered in the UDF

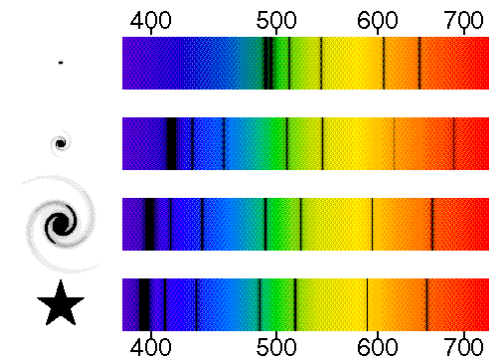
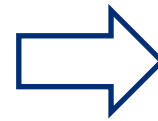


To explore the first galaxies, we need a big infrared telescope

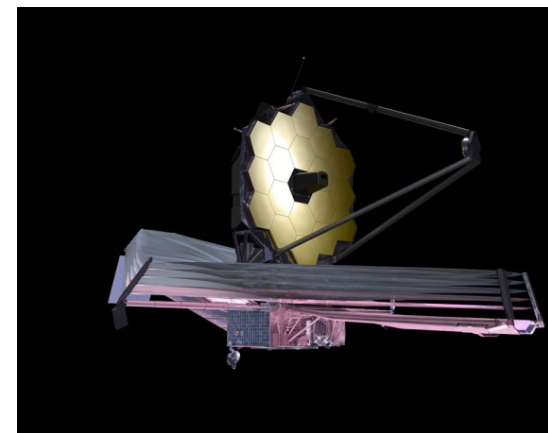
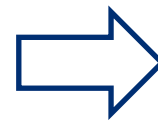
Distant galaxies are moving away from us with high velocity



So their light is red shifted into the infrared portion of the spectrum

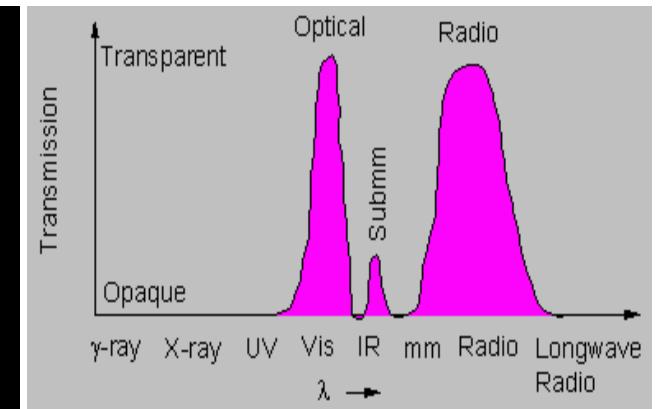
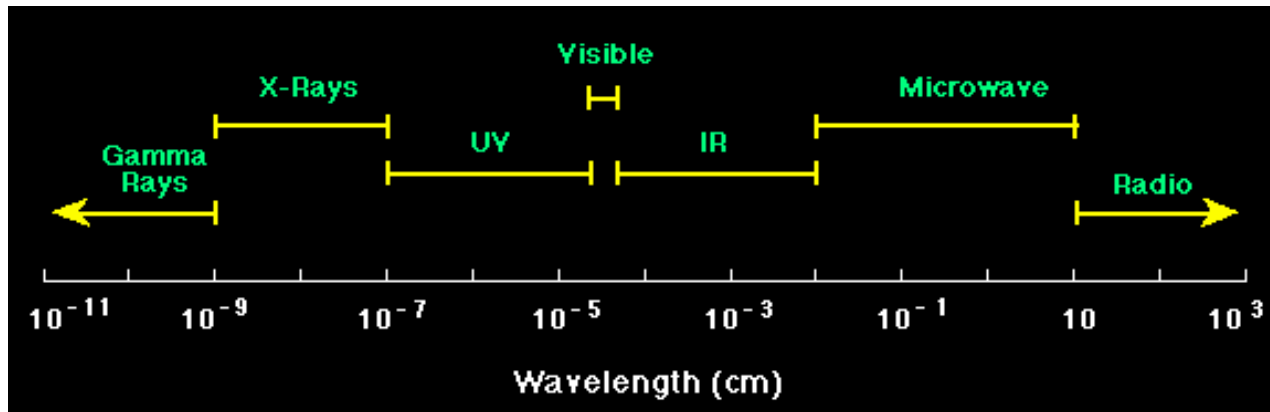


To image them, NASA is building a new telescope that is bigger than the Hubble Space Telescope and designed to observe infrared light



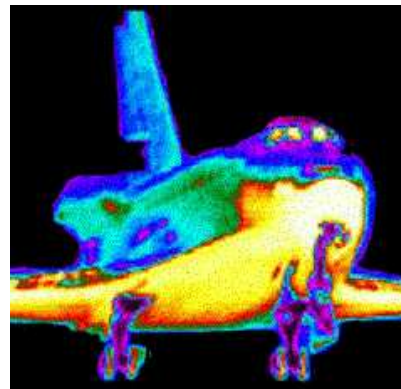
Light comes in more colors than our eyes can see

Light from the first galaxies is **redshifted** from the ultraviolet into the infrared.



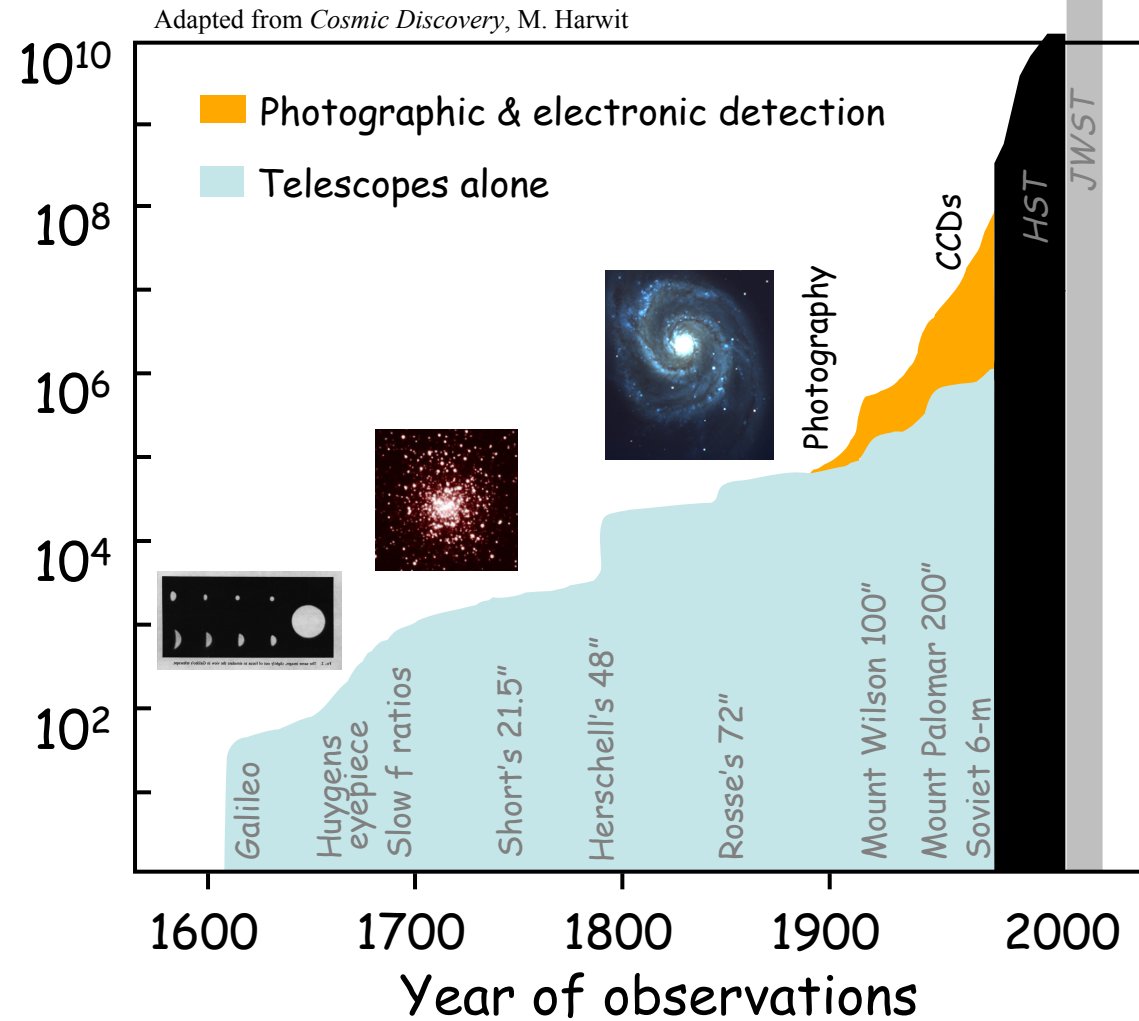
Infrared is heat radiation

Our eyes can't see it, but our skin can feel it



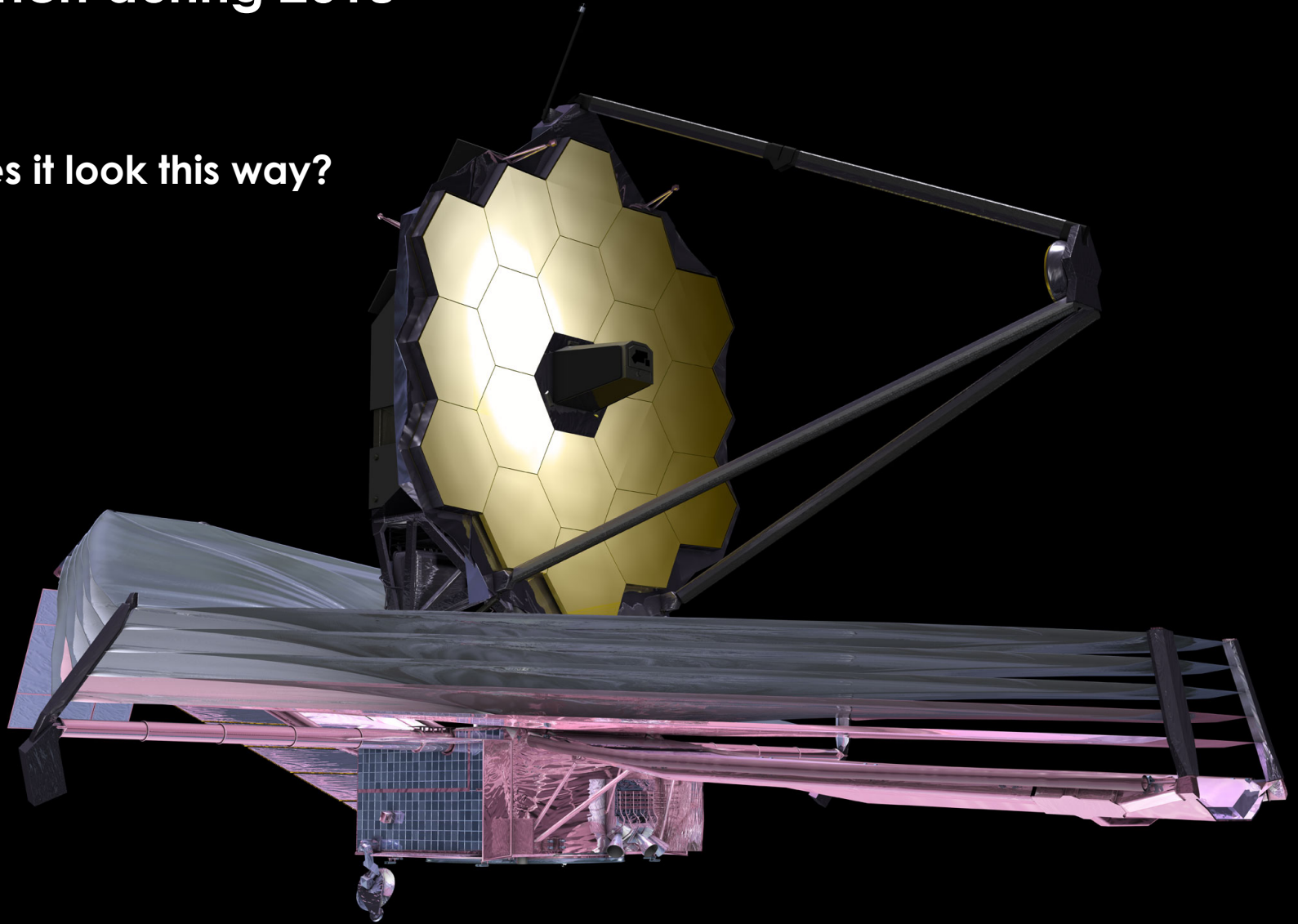
We also need electronic detectors that are more sensitive and can see more colors than the eye

Sensitivity
Improvement
over the Eye



The James Webb Space Telescope under construction for launch during 2018

Why does it look this way?



Who was James Webb?

James Webb (1906 – 1992):

Second Administrator of NASA (1961 – 1968)

Oversaw:

- first manned spaceflight programs: Mercury, Gemini, Apollo
- Mariner, Pioneer planetary exploration programs



Key features of the JWST that enable it to explore beyond the reach of all prior telescopes

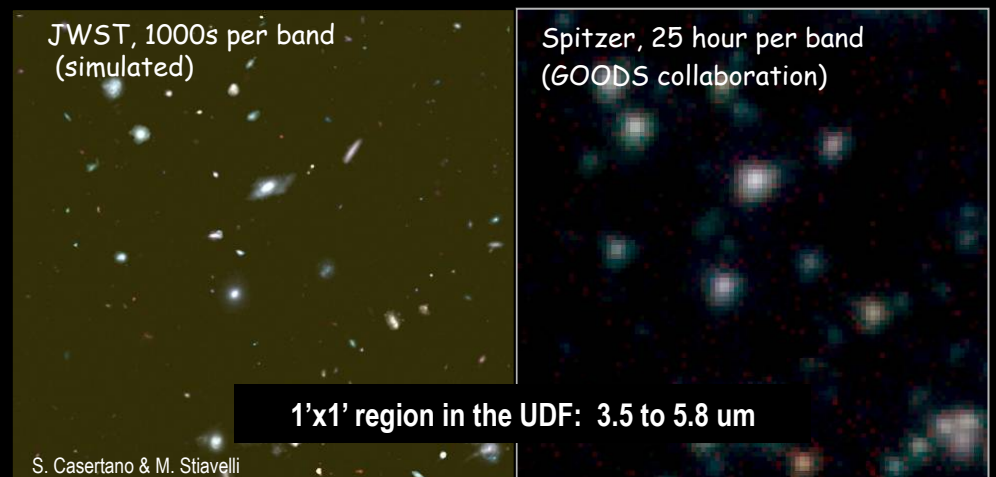
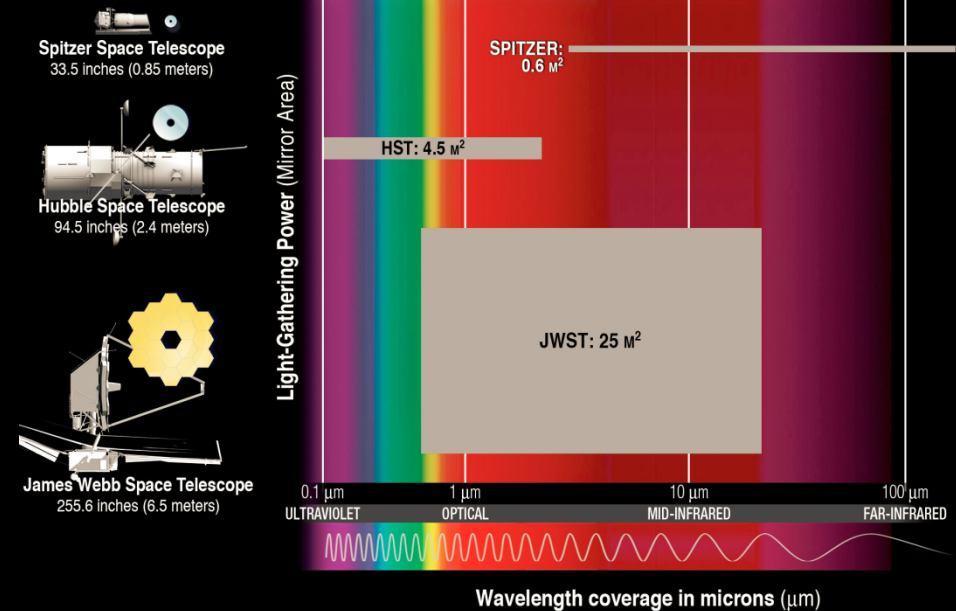
7X the light gathering capability of the Hubble Space Telescope

Wavelength coverage spanning the optical to mid-infrared spectrum

Similar angular resolution to HST but at longer wavelengths

As a consequence, the JWST requires:

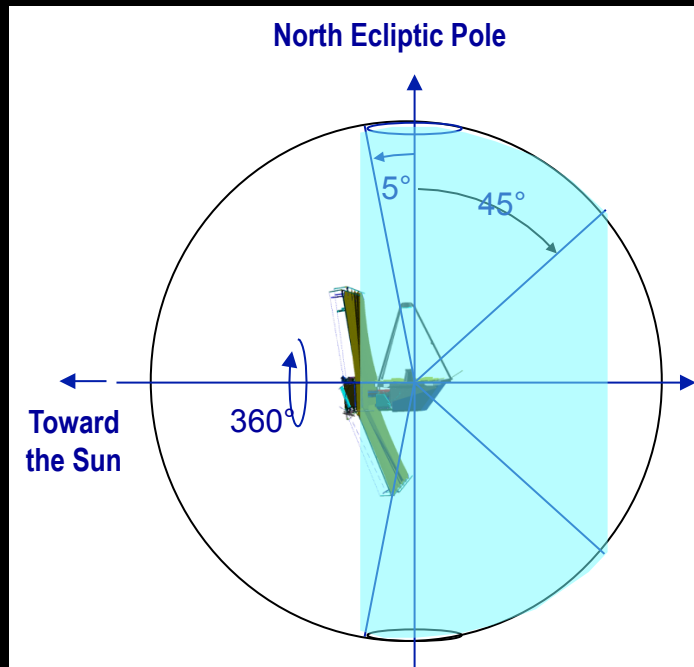
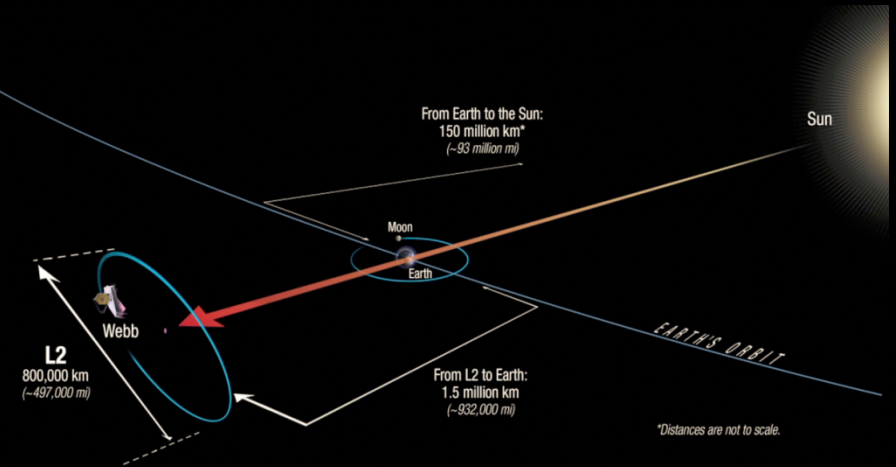
- A primary mirror that is larger in diameter than available rocket fairings
- A high stability 40-50 K (-380 F, -230 C) cryogenic operating temperature



The JWST will be placed in orbit about the Sun-Earth L2 point approximately 1.5 million km from Earth

An L2 point orbit was selected for JWST to enable passive cryogenic cooling

- Station keeping thrusters are required to maintain this orbit
- Propellant sized for 11 years
- ~100 day journey to the L2 point



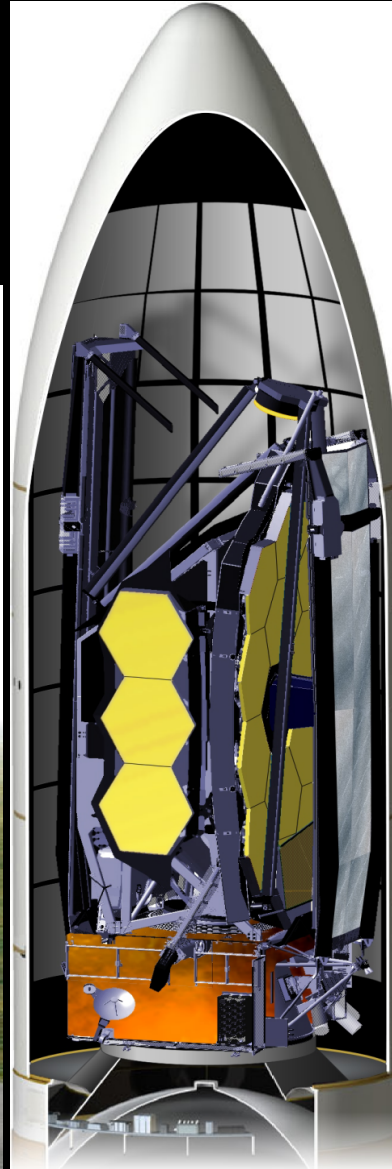
The JWST can observe the whole sky while remaining continuously in the shadow of its sunshield

- At any instant, the telescope can point at 35% of the sky
- The whole sky is covered each year with small continuous viewing zones at the Ecliptic poles

Fitting a 6.5 m diameter telescope into a 5 m diameter rocket requires a fold-up deployable architecture.



Ariane 5 ECA

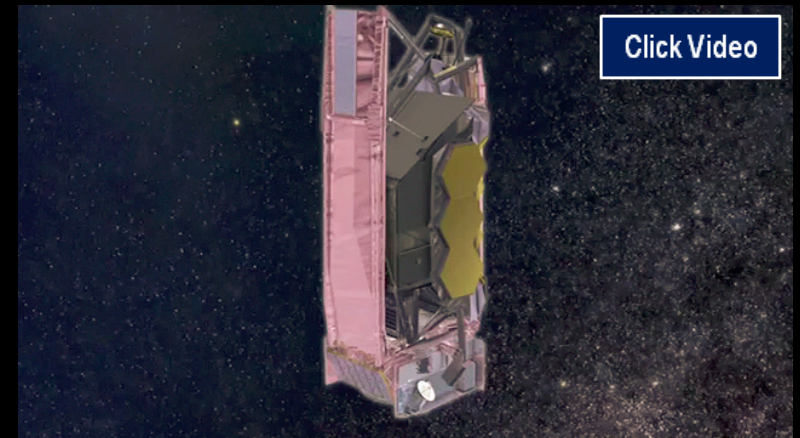


JWST is designed to integrate with an Ariane V launch vehicle

Launch from Kourou Launch Center (French Guiana)

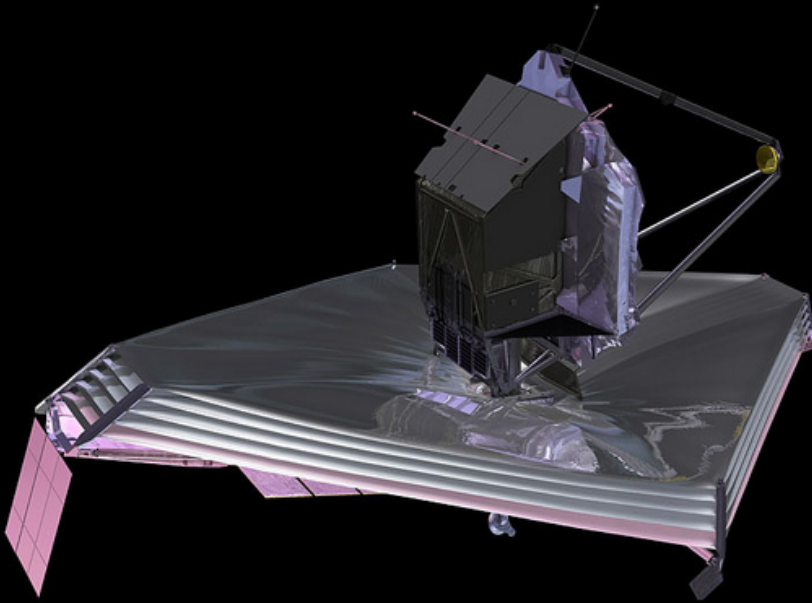


JWST payload: 6330 kg

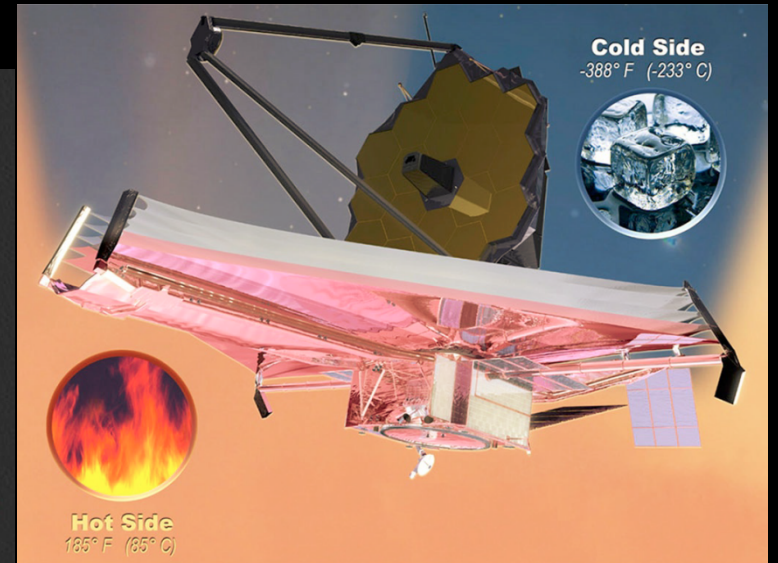
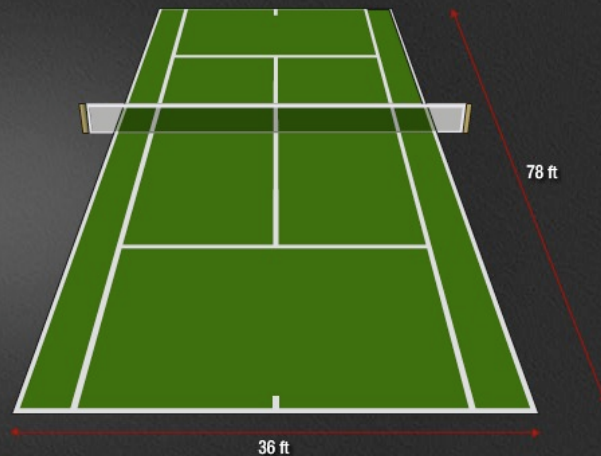
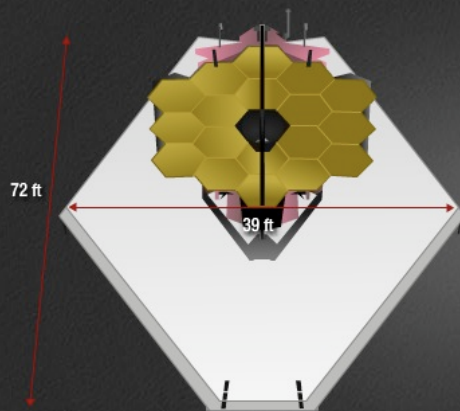


[Click Video](#)

The JWST's 5 layer sunshield has an SPF of $\sim 10^6$



The JWST is as large as a tennis court



Construction of the JWST is nearing completion and extensive testing for launch is beginning

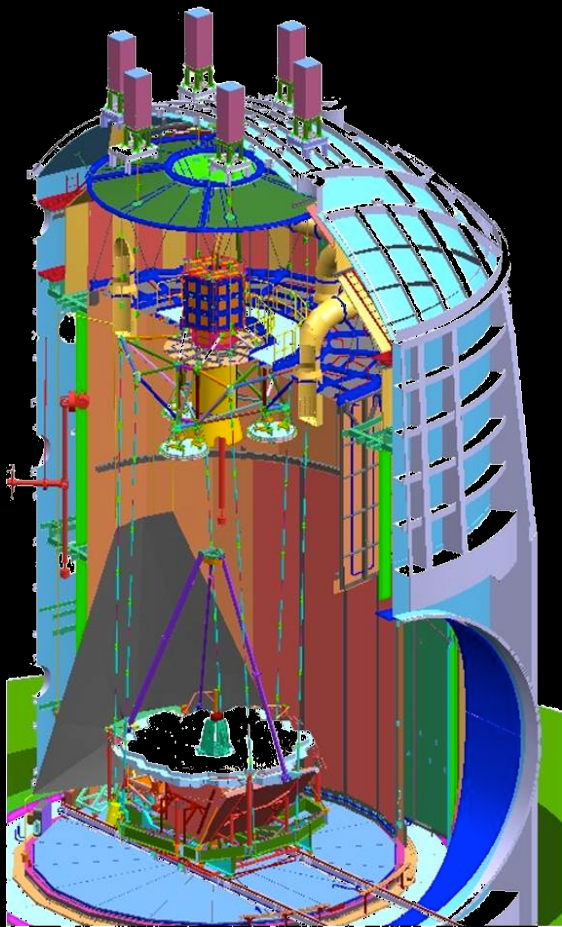


Testing the JWST requires the largest space simulation facilities in the world

Apollo era facility extensively refurbished for JWST

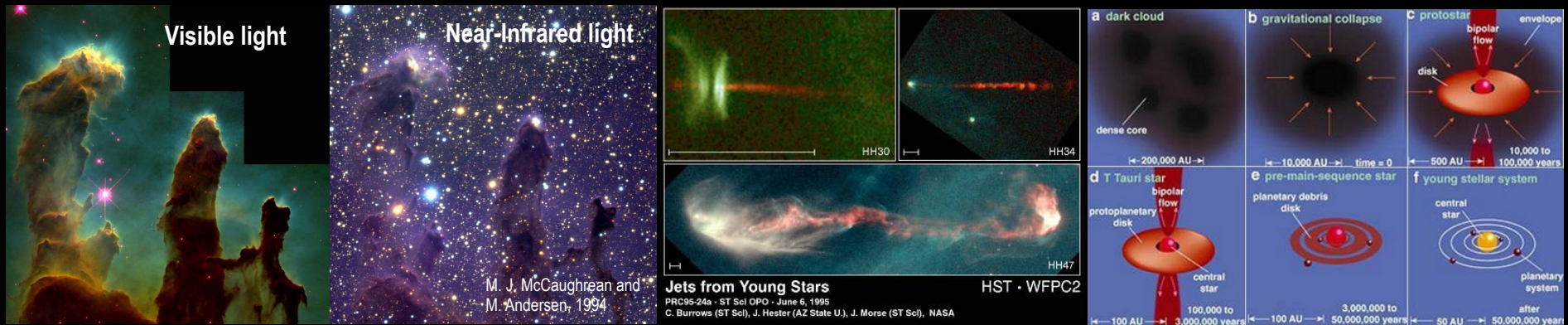
Largest deep cryogenic space simulation chamber in the world

Performance certification completed during Aug 2012

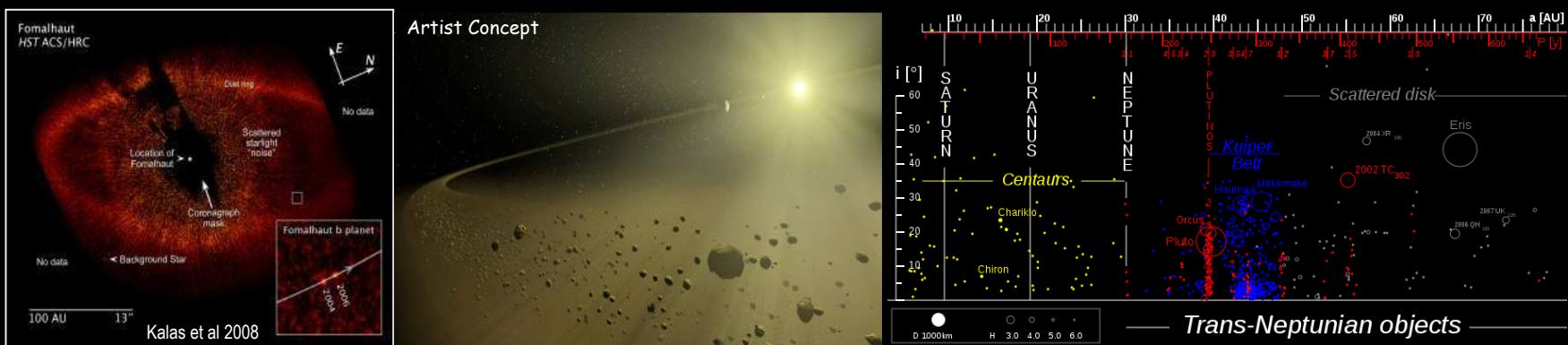


The JWST will advance understanding on a wide range of topics other than the early universe...

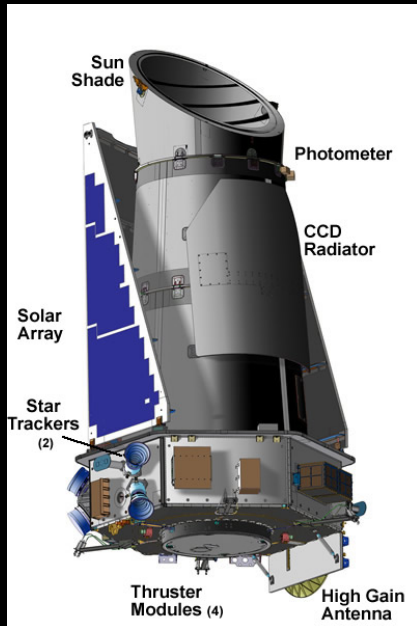
How do stars form?



How do planets form?

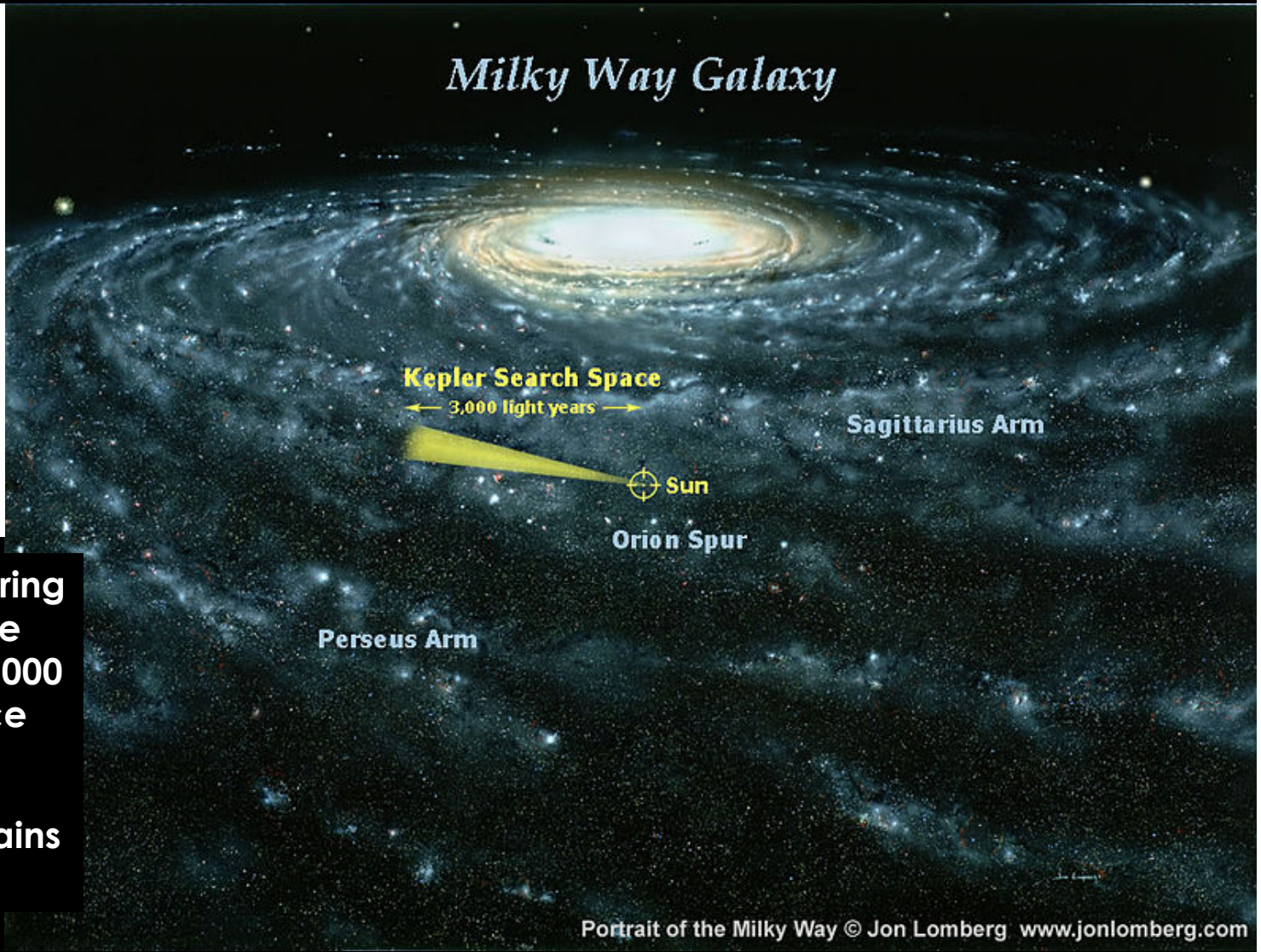


NASA's Kepler mission has shown that our galaxy contains at least 1.6 billion alien planets on which liquid water can exist!



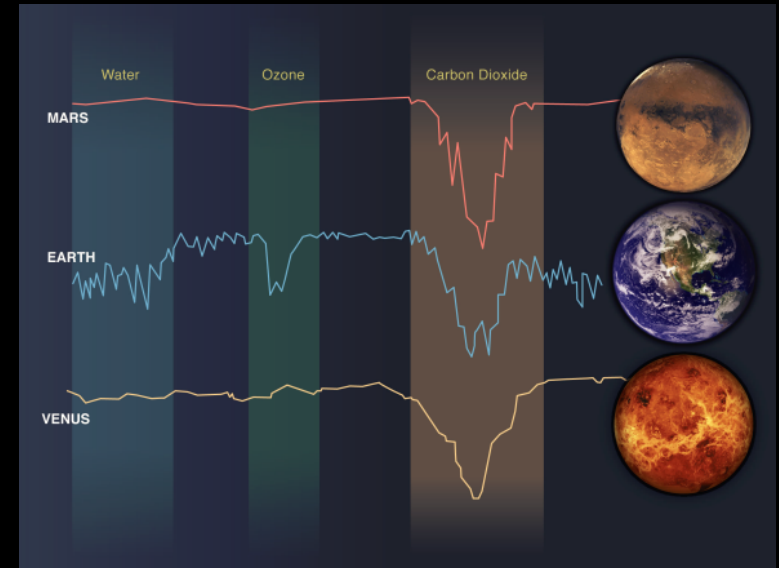
Kepler has been staring at one location since 2009 to monitor 100,000 stars for the presence of planets.

The Milky Way contains 100 billion stars.

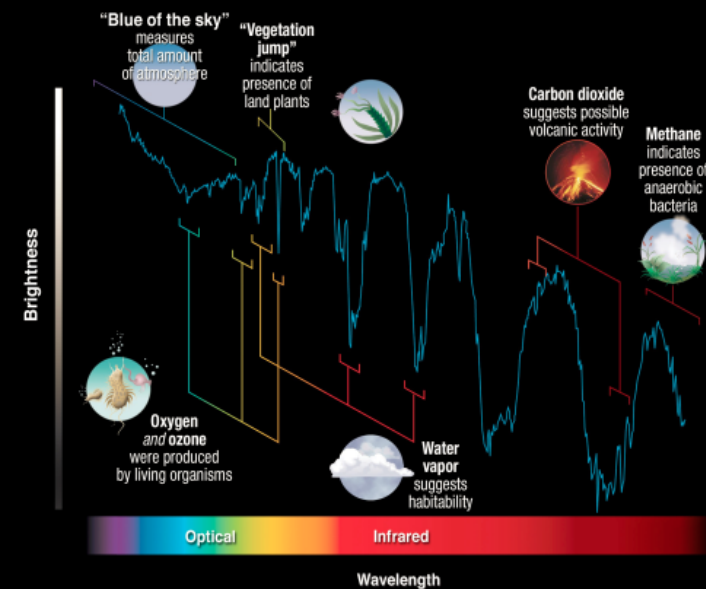


Some exoplanets have atmospheres

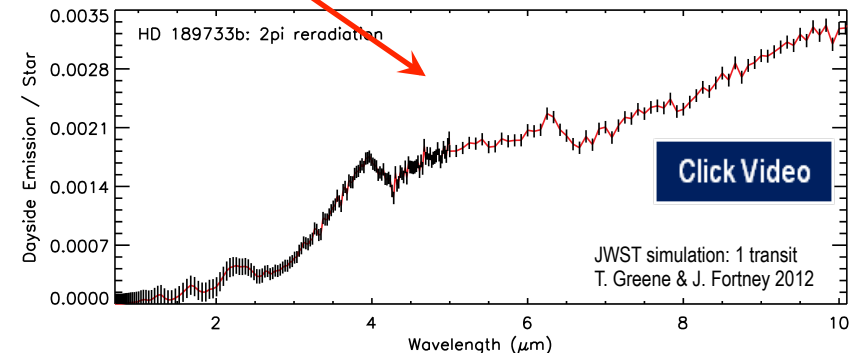
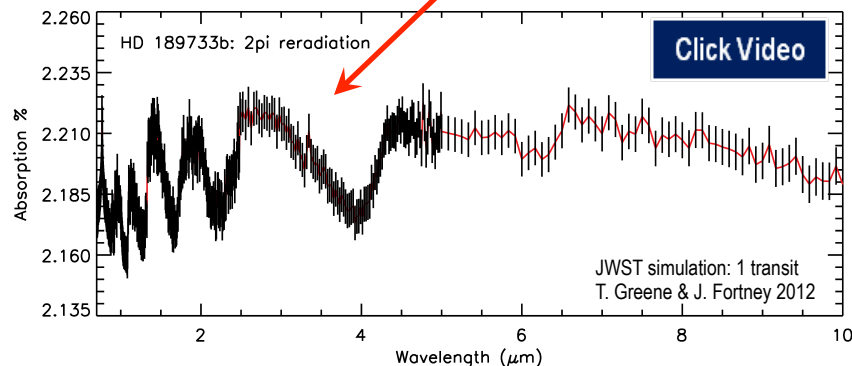
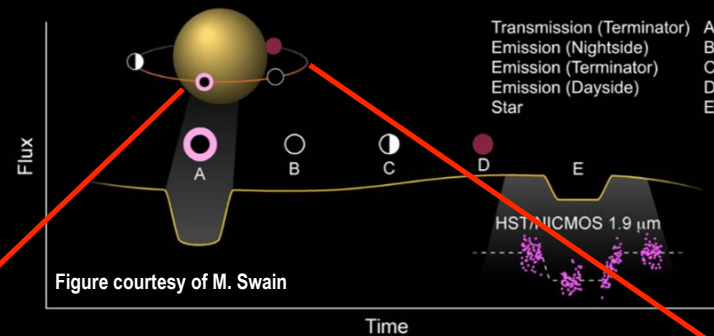
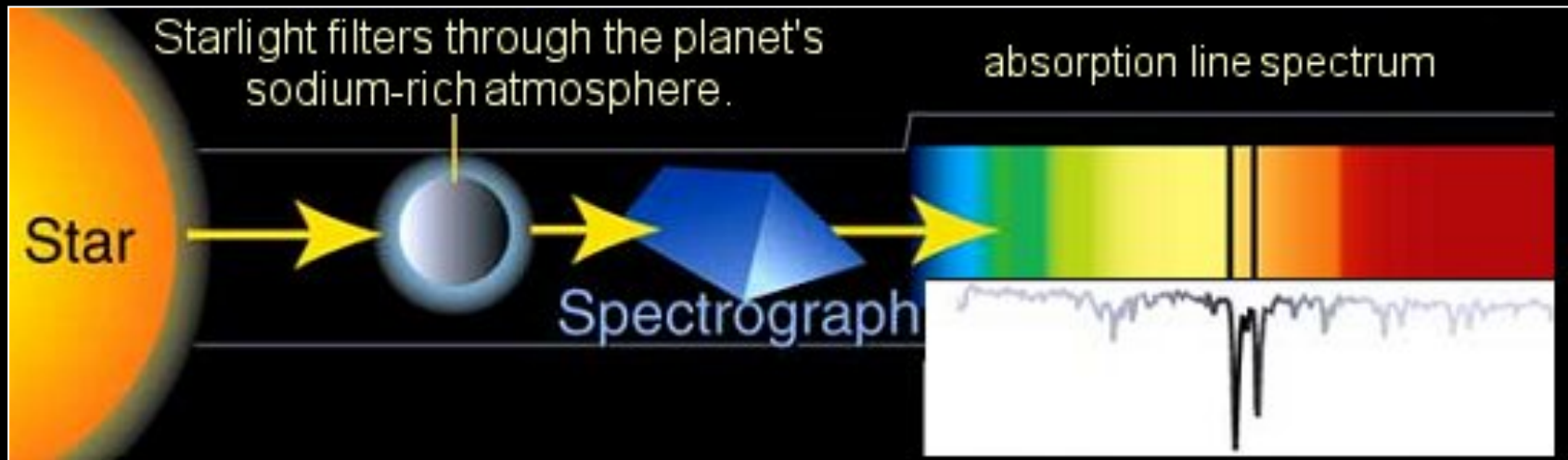
Composition of atmospheres
is revealed by spectroscopy



So is the presence of life!



JWST will characterize exoplanet atmospheres



There will be plenty of known exoplanets for JWST to observe when it is launched in 2018

Last Update: January 11, 2013

Number of Potential Habitable Worlds

Potential Habitable Exoplanets	Unconfirmed Potential Habitable Exoplanets	Predicted Potential Habitable Exomoons (2)	η_{Earth}
9	27	30	1.6 %

All Currently Known Exoplanets

Confirmed Exoplanets	NASA Kepler Candidates	Other Unconfirmed Exoplanets
859	2320	186

η_{Earth} is the minimum percentage of stars with habitable worlds

There are 100 billion stars in our galaxy → 1.6 billion habitable worlds

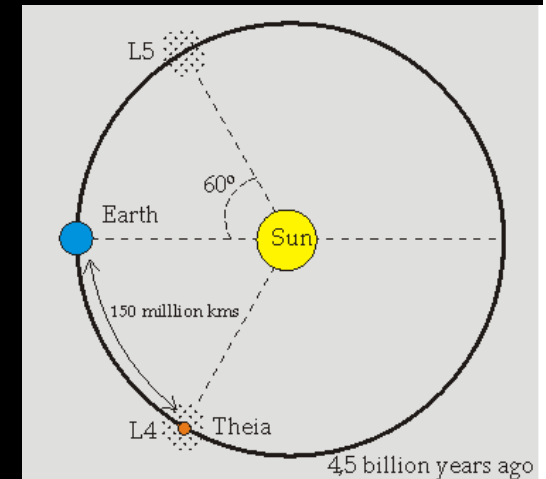
JWST has the sensitivity and stability for detecting LIQUID WATER on a planet a few times the size of the Earth

The JWST will study our solar system to learn how it and others evolve after their planets are formed

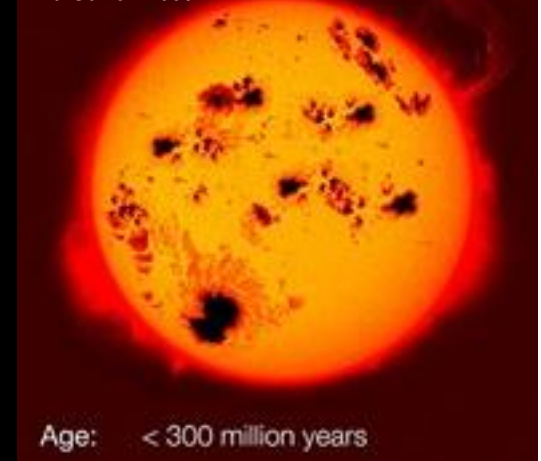
A possible history of the Earth:

- Sun and first solid bodies in Solar System 4.567 billion years ago
- Mars-sized body “Theia” hits Earth, melting everything, dispersing volatiles like C and H; debris forms Moon, 90 MY AF (after formation)
- Cool early Earth, possibly with water
- Jupiter, Saturn orbits switch (twice?), clear debris from solar system, cause “late heavy bombardment”, “Hadean” geologic period, many craters, new water and carbon delivery to Earth, 400 - 700 MY AF
- Life forms shortly after (~ 3.8 BY ago); all life uses same genetic code!
- Young Sun very active, gets steadily brighter with time, warming Earth
- 300 MY from now – Plate tectonics produce super continent
- 1 BY from now – Sun 10% brighter; Earth too hot for us
- 8 BY from now – Sun becomes red giant and engulfs Earth

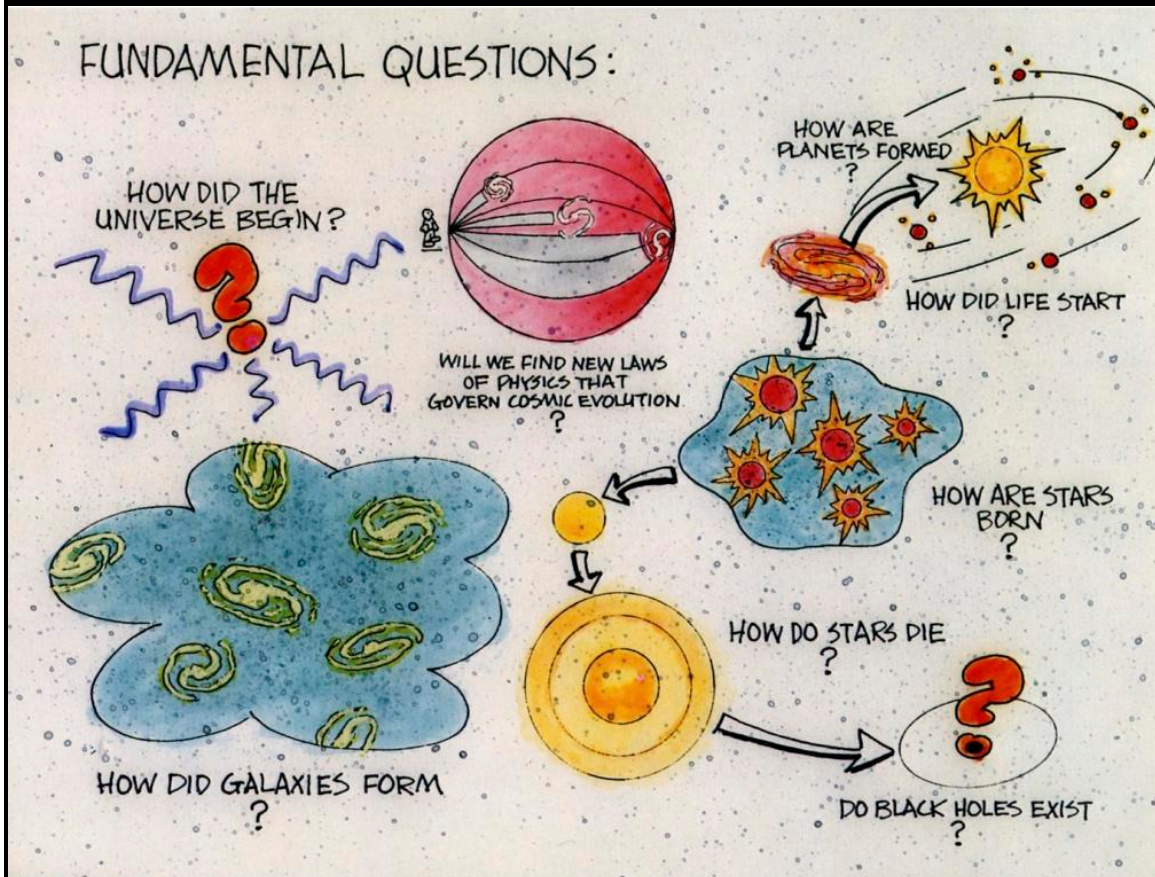
Hartman & Davis 1975

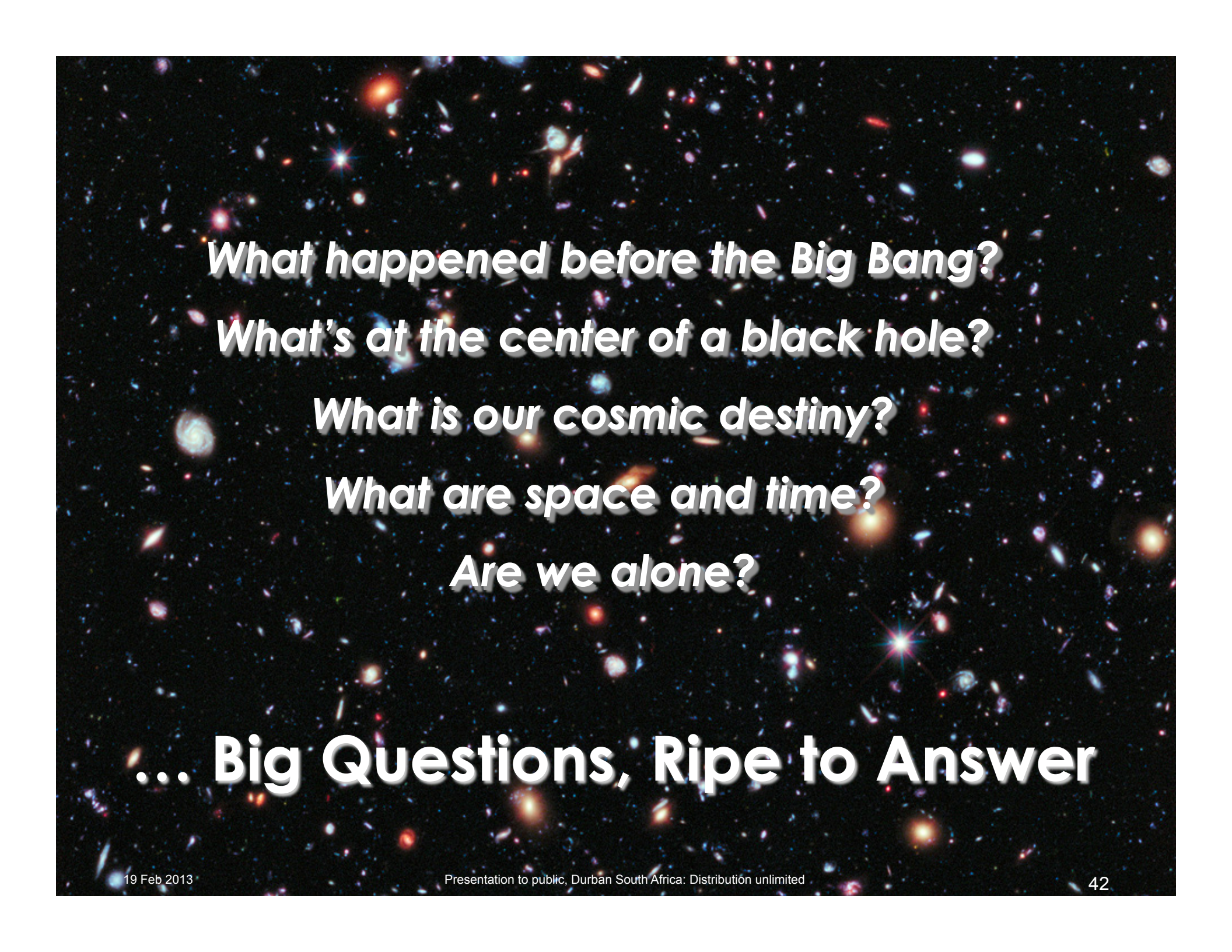


Ed Guinan 2009



Standing on his shoulders, future Einsteins are asking big questions ...





What happened before the Big Bang?

What's at the center of a black hole?

What is our cosmic destiny?

What are space and time?

Are we alone?

... Big Questions, Ripe to Answer

YOU can join the quest for answers

The scientists, engineers, and managers that use and build space observatory's come from all walks of life.

You can join them!

Go to college.

Study science, engineering, and math ...



JWST Astronomer
Dr Jane Rigby

JWST Astronomer
Dr Jason Kalirai

JWST Astronomer
Dr Amber Straughn

JWST Engineer
Robert Rashford

JWST Astronomer
Dr Jon Gardner

JWST Manager
Dr Kalyani Sukhatme

JWST Manager
John Durning

